CEMENTS AND ARTIFICIAL STONE

CEMENTS

AND

ARTIFICIAL STONE

A DESCRIPTIVE CATALOGUE
OF THE SPECIMENS IN THE
SEDGWICK MUSEUM, CAMBRIDGE

By the late

JOHN WATSON
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Preface

By Professor J. E. MARR, Sc.D., F.R.S.

THE author of *British and Foreign Building Stones* and *British and Foreign Marbles and other Ornamental Stones* left some manuscripts dealing with other portions of that fine collection of specimens illustrating the geology of building materials, which he was instrumental in bringing together in the Sedgwick Museum, Cambridge.

Of these manuscripts, the one which is here printed was essentially completed at the time of Mr. Watson's death in 1918. It has been carefully revised by the Editor, Dr. Rastall, and should be found useful by all who are interested in the subject.

This, and the previous works by the author, form a fitting monument to his devotion and unwearied industry in assembling the objects of the Sedgwick Museum collection.

Had he lived to see the publication of his work he would no doubt have made acknowledgment to those who gave him assistance.

JOHN E. MARR.

SEDGWICK MUSEUM,
CAMBRIDGE.
June, 192[illegible]

Author's Preface

THE art and science of cement making are undoubtedly more closely associated with applied chemistry than with geology, it is therefore with a certain amount of diffidence that I venture to introduce this descriptive catalogue as a supplement to those of "Building Stones" and "Marbles," which I have had the privilege of placing in the hands of the student of Economic Geology at this University. My reluctance, however, is minimized when the fact presents itself that, although the cement industry of the present day is largely dependent on the essential principles of chemistry, primarily the exploiters of the industry look to the student of geology for reliable information regarding the occurrence in nature, and the continuity of the supply, of the raw materials essential for the process of manufacture.

I have avoided as much as possible the introduction of details with regard to the chemistry of cement making, first, because I feel quite incompetent to treat the subject with anything like the justice it deserves; and, secondly, because I consider it out of place to attempt to deal at length with a branch of natural science which is not strictly affiliated with geology. For the benefit, however, of students and others who may desire to investigate the fundamental principles of the chemistry of cement making, I have ventured to introduce at the end of the catalogue, before the index, a bibliography of reliable text-books and other treatises relating to the manufacture and uses of cements, some of which deal almost exclusively with the chemistry of cement making. All of these works can be found on the shelves of the Cambridge University Library.

I should like to draw attention to the fact that the specimens in the collection, and described in the catalogue, represent only cements which are manufactured in the British Isles; but I hope that the day is not far distant when room will be allocated in this Museum for at least specimens of the raw materials, or natural rocks, suitable, and at present employed, for cement making in all parts of the world. With this innovation in prospect I invite additional benefactors interested in the manufacture to send in specimens, as being one method of helping to further the object I have in view, namely, to make the collection useful to all students of economic geology, whether British, Colonial, or Foreign.

In conclusion I venture to assert with confidence, based on many years of practical experience, that there is no branch of industry in the world that presents a wider field of research to the student of Economic Geology, Applied Chemistry, Architecture, Engineering, and other allied sections of Natural Science, than that of Cement, its Manufacture and Uses.

J. W.

BRACONDALE,
CAMBRIDGE, 1918

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Introduction

THE term "Cement," in a general sense, is somewhat vague, and covers a wide area in the economics of the present day. It may be expected, however, that specimens of cements exhibited in a geological museum must be essentially of a lithological character, and derive their origin from matter directly connected with the science of geology. The description of the specimens in the Museum will prove such to be the case.

No geological sequence has been followed in the arrangement of these specimens, as was the case with the "Building Stone" collection, neither has any particular geographical order been adopted, such as will be found with the specimens of "Marble and other Ornamental Stone." Moreover, the collection is confined to the cements that are produced and manufactured in the British Isles.

Portland cement takes precedence in the catalogue, not because it can boast of the same antiquity as some other cements described, but because the magnitude of that branch of industry far surpasses the manufacture of any other cements obtained in the British Isles; in fact so widely is Portland cement known in all branches of construction that the term "Cement" is generally understood to have reference to Portland cement, and the reader will be alive to the fact, after having perused the following descriptive notes, that other hydraulic cements which formerly held prominent positions in the industrial world for structural work, are now in a state of decline, or have ceased altogether to be manufactured, Portland cement having taken their place.

It may be useful to point out in these introductory remarks the analogy that exists between what is generally classed as cement and what is known as lime. Pure calcium oxide (quick lime or "fat" lime), when moistened, combines with the added water, evolves much heat, and almost immediately falls into an impalpable powder, forming slaked lime, which is equivalent, chemically, to the conversion of the oxide into a hydrate. Cement, on the other hand, commences to harden or "set" on the addition of water, without any previous slaking action taking place.

There are, however, impure limes that contain appreciable proportions of argillaceous matter, which, when water is added, slake very gradually and imperfectly, evolving a minimum of heat in the process. This variety is distinguished as Hydraulic Lime; and, in some instances, where the hydraulicity is profound, they do not admit of being slaked at all, and are sometimes classed commercially among cements.

In reference to the chemical analyses and other formulæ enumerated in the following details, it must be understood that they are not guaranteed to represent the analysis of each particular specimen exhibited, but they must be considered as only typical of the class of rocks and manufactured material that the specimens are intended to represent.

Portland Cement

TRUE Portland cement is an artificial hydraulic cement produced by a mechanical incorporation of carbonate of lime and silicate of alumina, which are then chemically combined in the calcining stage of manufacture, and the resultant product reduced to a fine powder. Geologically the forms of the above-mentioned raw materials vary considerably, depending upon the nature of the rocks available in the locality where the manufacture is carried on. Those employed in the British Isles will be referred to in detail when describing the specimens in the collection. Before, however, proceeding to do so it may be helpful if a few historical facts are mentioned relating to the manufacture of hydraulic cement, and to the introduction and development of Portland cement.

Historical Notes

From time immemorial engineers, architects, and others interested in materials of a lithological nature suitable for structural work have known that the incorporation of certain rocks of a siliceous and argillaceous nature, if pulverized and judiciously mixed with pure lime mortar, enhances its value for hydraulic work. During the classical age Roman builders gave much attention to this characteristic; and while being convinced that the purer the carbonate of lime they procured for their purpose the more valuable it was, used large quantities of a soft and vesicular variety of the ejectamenta of volcanoes which abounds in southern Europe,

notably in Central and Southern Italy, and is known as Pozzuolano; and this they mixed with the lime produced from the pure carbonate of lime obtained from the Apuan Alps, when a mortar for hydraulic work was required. Indeed, the Romans became so convinced of the importance of this manipulation that they considered a mixture of Pozzuolano improved their mortar for building of all kinds, whether hydraulicity was essential or not. Vitruvius states that the Romans used Pulvis Putevolanus, which was found on the slopes of Mount Vesuvius, together with lime and small stones, for constructing moles, quays, and other works in the sea and under water.*

Coming to more modern times, Smeaton, of lighthouse fame, profiting by what he gathered from the writings of Vitruvius and other classical authors, when selecting and preparing suitable material for the erection of the celebrated Eddystone Lighthouse, expended much labour and time in the investigation of the rocks which he believed to be most suitable in order to obtain a reliable hydraulic mortar, at that period known as "Water Lime," with which to construct the lighthouse. Smeaton commenced his experiments and investigations about the year 1757, and persevered with them over a lengthened period. It is beyond the scope of these brief notes even to summarise the information he gathered, or describe in detail the conclusions he arrived at from his exhaustive labours, but it would be time well spent if the student of economic geology were to study Smeaton's interesting account of his investigations. Suffice it to say that he proved to his own satis-

* Putevolano is the ancient name of Pozzuoli, a town on the north bay of the same name, being a portion of the Bay of Naples.

faction that the purity of the carbonate of lime employed for the selection and production of Water Lime was not of the importance that the Romans attached to it, and this led him to state in his writings that "an admixture of clay in the composition of a limestone might be the most certain index of the validity of a limestone for aquatic buildings."*

In 1796 James Parker, residing in Surrey, doubtless benefiting by the knowledge gained from Smeaton's exhaustive experiences, took out a patent for the manufacture of "a cement to be used in aquatic and other buildings and stucco work." Parker had found that there were certain rock deposits containing a homogeneous admixture of the elements requisite for the manufacture of hydraulic cement. These were septarian nodules found embedded in the gravel deposits of the Kentish coast, and chiefly on the Island of Sheppey. These Parker calcined in a lime-kiln, subjecting them to a heat, as the specification provides, stronger than that used for burning lime, but not sufficient to vitrify them. Subsequently Parker termed his new invention "Roman cement"; this, however, will be referred to later when the specimens representing that cement in the collection are described.†

In the year 1818, Vicat, an engineer of some reputation in France, introduced a cement which he called hydraulic lime, and which he described as being composed of ground chalk mixed with a requisite proportion of clay, which, after being mechanically mixed and moulded into blocks, was burnt in kilns and subsequently ground. This seems to be the first authenticated example of the

* Smeaton's *Narrative of the Building of Eddystone Lighthouse.*

† See page 105.

manufacture of a hydraulic cement of the Portland type, i.e. the admixture of calcium carbonate with the silicates of alumina by artificial means, and subsequent chemical combination by calcination. A manufactory was established at Meudon, a small town about three miles southwest of Paris, but this, for some reason, did not meet with the success anticipated.

In 1822, James Frost, of Finchley, in Middlesex, claimed to have invented a new hydraulic lime or cement. The raw materials he employed were carbonate of lime obtained from the Upper Chalk beds of the Thames valley, and the alluvial deposits on the marshes at Gillingham, a district on the banks of the river Medway. Frost specified that the mixture, to obtain a good result, must be two parts by weight of chalk to one part of clay. These were mechanically mixed, and reduced to the consistency of cream by the addition of water in a mixing mill. This fluid was then pumped into settling tanks, and remained there until it was sufficiently consolidated by evaporation to be dug out and transported to drying sheds, where the remaining moisture present was dispelled by the action of the atmosphere. When sufficiently dried, it was then calcined in an ordinary limekiln, the heat generated being just sufficient to drive off the carbonic acid gas, great care being exercised that none of the material was vitrified, the resultant product being a light yellow corky material. This was subsequently ground and sold as "Frost's Cement."

It was fairly hydraulic, very quick-setting, and for some time commanded a ready sale. Since, however, the introduction of Portland cement, the demand for Frost's cement began to decline, and it has now ceased to be manufactured; a specimen therefore, does not appear in this collection of cements.

In the year 1826, the Duke of Wellington, then Master-General of the Ordnance of this country, gave instructions that practical architecture should form a branch of study at Chatham. Major-General Pasley, Director of studies at Chatham, under whose care the junior officers of the Royal Engineers were being instructed, commenced a course of investigations, coupled with exhaustive experiments, to elucidate the properties of hydraulic cement. Based principally on the information he gathered from the researches of Smeaton, he selected carbonate of lime and silicate of alumina, in the form of chalk and clay, as his raw materials to be experimented upon, the former being from the beds of the Upper Chalk series of the district, and the latter a loamy clay belonging to the London Clay beds of the Thames basin, which is largely used for making building bricks, and which he obtained from a local brick works. Most of General Pasley's experiments, however, were failures, and he was never able to guarantee a reliable hydraulic cement. The presence of a large proportion of coarse free silica, quartz and flint, in the London Clay, which would not combine chemically with the lime in calcination, was probably the chief cause of his failures; and although later he employed the more plastic clay from the alluvial deposits of the Medway, he never was able to guarantee a good hydraulic cement; moreover, he followed the example of the manufacturers of Frost's cement, and deliberately rejected any of the calcined material that approached the stage of vitrification.

While these efforts were being carried on in the south of England and in France, similar attempts were being made in the north of England.

In 1824, Joseph Aspdin, a builder in Yorkshire, secured a patent for manufacturing a cement or artificial stone,

for stuccoing buildings, constructing water-works, cisterns, &c., and called it Patent Portland Cement, owing to its resemblance in colour, when moulded, to the well-known Portland Stone of Dorsetshire. Aspdin's method of procedure, set forth in his specification, was to employ the road scrapings accumulated on the road-sides in the neighbourhood of his lime-kilns, a material largely composed of calcium carbonate, the roads being repaired with the limestone occurring in that county; to this he added a proportion of argillaceous earth or clay, and then calcined the mixture in an ordinary lime-kiln, specifying that the heat generated must not exceed that which is sufficient to drive off the carbonic acid gas in the mixture. The specification is vague and misleading. No definite proportion of the two materials is mentioned; moreover, a much higher temperature must have been employed than that specified, because without incipient fusion of the materials Aspdin could not have produced a material that resembled in colour Portland stone. Suffice it to say, however, that Aspdin produced a cement that gave satisfaction, both for the manufacture of artificial stone and of hydraulic cement, and he established a small works in the neighbourhood of Wakefield. Besides being used locally, there are records of its employment by Brunel in 1828 for the construction of the Thames tunnel.

Aspdin's son William, ascertaining that the demand for hydraulic cement in and about London exceeded the supply, arranged with his father to manufacture his Patent Cement in the London district, and proceeded to erect a small manufactory at Rotherhithe. History does not relate whether the road scrapings of Yorkshire were transported to the Thames for the manufacture, but in a short while Aspdin removed his sphere of

operations to Northfleet, a district on the south side of the Thames a few miles higher up the river than Gravesend. This was the district where Frost's Cement, Roman Cement, as well as other cements for structural purposes, were chiefly manufactured. Aspdin, junior, probably being alive to the fact that his father's patent was vague and capable of being questioned, sought to surround the process of his manufacture with mystical operations known only to himself, in which even his own men were not privileged to share. It, however, soon became known that Aspdin was using a certain proportion of the Upper Chalk and the alluvial clay in his manufacture, in fact the same materials that were being employed for the manufacture of Frost's Cement, as well as Pasley's. To these were added certain materials transported from the north of England by sea, which were said to come from the blast furnaces of that region. This naturally raised the curiosity of the rival cement makers on the Thames; and as the new "Portland" was finding favour among engineers and others, some of them became alarmed at the competition they were destined to face. Among them were Messrs. White, who were the chief manufacturers of cement in the district.

The practical part of their works was under the management of Mr. I. C. Johnson, and he was instructed by his principals to use all legitimate measures to find out the supposed secrets hidden in the manufacture of Aspdin's new cement. Among other expedients, Johnson obtained a sample of the cement and submitted it to a chemist in London to be analysed. The following is a copy of the analysis:

$Ca_3(PO_4)_2$	45·00	Al_2O_3	1·00
CaO	22·24	H_2O	1·00
$CaCO_3$	10·00	Soluble saline matter	2·50
$CaSO_4$	15·00	H_2SO_4	a trace
FeO	3·26		
			=100·00

It will be observed that a considerable proportion of calcium phosphate is present. Johnson was sufficiently conversant with the chemical constituents usually found in Thames Chalk and Medway Clay to know that calcium phosphate did not exist in appreciable quantities in these two raw materials; believing, therefore, that the addition of phosphorus in some form or other was the secret he was endeavouring to elucidate, he was advised to add a proportion of bone-ash to his cement to make up the deficiency. A quantity of old bones were therefore procured, which were calcined and pulverised and added to the mixture. The result proved to be a failure.*

Meanwhile obstacles and discouragements presented themselves, tending to retard the successful introduction of true Portland Cement. Rumours were afloat among the members of the building trade and architects that unreliable samples of Aspdin's Patent Cement were being placed on the market, and that in numerous instances it was proving to be a failure. One instance which occurred at Pimlico may be cited. A terrace of large and lofty houses had its heavy projecting cornices and chimney stacks made of Aspdin's artificial stone. Shortly after the completion of the houses the ornamental cornices, chimneys, and other external decorations made of the cement cracked and twisted, and eventually fell to the ground, the houses presenting the appearance of a modern ruin. This, with other similar catastrophes, served to condemn the new cement almost beyond hope of recovery.

Notwithstanding these drawbacks, Johnson persevered with his experiments, and what was thought to be

* Subsequently the London chemist admitted that the analysis was incorrect.

an accident at the time proved to be a solution of the problem of Portland cement manufacture. On one occasion the produce of a kiln was so highly calcined that practically the whole of the material was in a state of semi-vitrification. Johnson had the curiosity to pulverise some of this, and to his surprise he found that when made into a paste it turned very hard and assumed the colour of Portland stone. He, however, was disappointed to find that it fell to pieces when the set cement was immersed in water. To quote Johnson's own words to the writer, he said: "I was so ashamed at this signal failure that I had the product of this kiln hidden away in an isolated cellar or vault at the outskirts of the works near the river out of sight." Some weeks after, Johnson when passing the spot, had the curiosity to look into the vault, when he saw that the hard lumps of clinkered material had disintegrated. The damp atmosphere of the cellar had acted upon the free lime present, and slaked it. Johnson again tried this material, and to his delight found it turned perfectly hard when pulverised and mixed, and proved to be thoroughly hydraulic. This was the turning point in Johnson's experiments, as he then grasped the necessity of having a degree of temperature in the calcination sufficiently high to produce a dense dark green clinker (see specimen No. 6), but of avoiding over-burned clinker, which resembles blast furnace slag and lacks hardening and hydraulic properties when pulverized. He also assumed that a carefully balanced proportion of the raw materials was essential to attain a successful chemical combination of the whole mass in order to produce a reliable hydraulic cement which must also possess a colour resembling that of Portland stone.

Johnson's assumption proved to be correct, and in a

short time, about the year 1845, his employers were in a position to guarantee a regular supply of reliable Portland cement. This was soon supplemented by the output of numerous manufactories that were established on the banks of the Thames and Medway, and in an almost incredibly short time the manufacture of Portland cement became the staple industry of that region.

It is interesting to record that the reputation among Government officials of what came to be known as London Portland cement was first established in France, as the following facts will demonstrate:—Messrs. White, the firm of manufacturers whose works Johnson supervised, were, as previously mentioned, extensive makers of Frost's Roman and other hydraulic cements, and exported large quantities to France for the use of maritime and other undertakings connected with the Government of that country. Samples of the new Portland cement were submitted to the French Government engineers, who subjected them to rigorous tests, the results of which were so satisfactory that they ordered a small cargo to be sent to Cherbourg, where extensive operations were going on for the construction of the celebrated harbour works and fortifications at that port. A system of tests was subsequently established, based on the results gained from that cargo, and very many ship-loads were sent in quick succession, guaranteed to fulfil the specified requirements. These harbour works were publicly inaugurated in 1858, in the presence of the late Queen Victoria, and are a striking illustration of an early, if not the first, maritime undertaking where British Portland cement was extensively employed. Several works of great magnitude, both for British and Foreign Governments, followed, in the construction of which London Portland cement formed an important feature.

Upwards of 20,000 tons of British-made Portland cement were sent to construct the docks at the Port of Le Havre from 1865 to 1871. It is instructive to record that the standard specification of tests issued by the French engineers at Cherbourg was almost without exception adopted, and continues to be in general use with sundry additions compatible with the many improvements since introduced in the manufacture, which will be referred to later.

Such, then, is a brief outline of the early development of hydraulic cement of the Portland type. A reliable statistician has lately estimated that at least twenty millions of tons of Portland cement are now produced annually throughout the world, and it may be safely stated that few, if any, branches of manufacture have expanded so rapidly in the comparatively short period of little more than half a century. It is also fair, in justice, to add that, although the name of Joseph Aspdin is justifiably coupled with the invention of the cement, as set forth in his patent dated the 24th October, 1824, the foregoing facts lead up to the assumption that, had it not been for the persistent perseverance of Johnson, backed by the enterprise of his employers, Portland cement would have sunk into oblivion.*

* Mr. Johnson subsequently severed his connection with Messrs. White, and established extensive works on the banks of the Thames and on the Tyne, which are now absorbed in a syndicate that controls a considerable proportion of the Portland cement manufactured in the British Isles Mr Johnson died in 1911 at the mature age of 100 years Some little time after the catastrophe at Pimlico mentioned above, Mr. Aspdin, junr., ceased to manufacture cement at Northfleet, and returned to the North.

Process of Manufacture

Specimens 1–12, illustrating the raw materials, process of manufacture (wet method), and finished Cement, made from Chalk and Clay.

Presented by Messrs I. C. Johnson & Co., Ltd, London and Gateshead.

No. 1. White Chalk, Chalk Quarries, Greenhithe, Kent.

Chemical Composition.

$CaCO_3$ 97·31, SiO_2 1·56, $Al_2O_3+Fe_2O_3$ 0·38, $MgCO_3$ 0·41 = 99·66.

No. 2. Medway Clay, Salt Marshes, Gillingham, Kent.

Chemical Composition.

SiO_2 58·70, Al_2O_3 16·48, Fe_2O_3 6·27, CaO 2·30, MgO 2·06, SO_3 0·34, S 0·52, Alkalies 3·63, loss 9·70 = 100·00.

No. 3. Boulder Clay, Clay Pits, Redheugh, near Gateshead-on-Tyne.

Chemical Composition.

SiO_2 56·71, Al_2O_3 18·62, Fe_2O_3 7·10, CaO 1·94, MgO 2·19, H_2O and organic matter 12·10 = 98·66.

No. 4. Chalk and Tyneside Boulder Clay, mechanically mixed with water and dried, ready for calcining.

No. 5. Chalk and Medway Clay, mechanically mixed with water and dried, ready for calcining.

No. 6. Chalk and Medway Clay, Calcined, known as **Cement Clinker.**

No. 7. Crushed Portland Cement Clinker, preparatory to grinding.

No. 8. Rotary Kiln Clinker.*

No. 9. Finished Portland Cement, Ordinary Grinding, ground to a fineness that leaves not more than 10 per cent. on a sieve having 5800 meshes per sq. inch.

Chemical Composition.

CaO 62·95, SiO_2 23·39, Al_2O_3 6·15, Fe_2O_3 2·95, MgO 1·10, SO_3 1·41, loss 0·36 = 98·31.

No. 10. Residue from Finished Portland Cement, Ordinary Grinding.

No. 11. Finished Portland Cement, Fine Grinding, ground to a fineness that leaves a residue of not more than 10 per cent. on a sieve having 32,000 meshes per sq. inch.

No. 12. Residue from Finished Portland Cement, Fine Grinding.

A brief description will now be given of the foregoing specimens, with some remarks on the process of manufacture.

No. 1. White Chalk, CHALK QUARRIES, GREENHITHE-ON-THAMES.

This is an example of the rock belonging to the Upper Chalk series of the Cretaceous system, which occurs and is exposed on the north and south banks of the Thames

* This specimen was presented by The British Portland Cement Manufacturers, Ltd., London.

east of London. The chemical analysis indicates that it is almost entirely composed of $CaCO_3$. The donors of these specimens use this variety of chalk both at their Thames and Tyne works, it being transported to the latter by sea.

No. 2. Medway Clay, SALT MARSHES, GILLINGHAM, KENT.

The alluvial deposit lining the estuary of the river Medway in the county of Kent, and known locally as "Medway mud," which is a salt water deposit, is considered to be one of the most valuable materials in the south of England for the manufacture of Portland cement. Doubtless these deposits were originally selected by the exploiters of the manufacture owing to their previous adoption by Pasley, Frost, and others for making their hydraulic cements, to which reference has already been made. Medway mud must not be confounded with the loamy brick-earth of the London Clay beds occurring in the London Basin series of rocks, which is so extensively employed for brick making. The London Clay deposits contain a large proportion of free silica in a coarse state of division, which does not combine chemically with the lime in the process of calcination; therefore, as was previously explained, it is not suitable for cement making. It may, however, be stated that experience has proved that the presence of a moderate percentage of free silica in clay, in the form of sand, does not condemn the material for cement making, providing that the sand is in a very fine state of division. If such be the case, the free silica combines readily with the lime in the process of calcination, when a temperature sufficiently high to cause incipient fusion of the mass is employed.

No. 3. Boulder Clay, REDHEUGH PITS, NEAR GATESHEAD-ON-TYNE.

For a considerable time after the reputation of Portland cement had been established it was believed by both manufacturers and users of the cement that Thames Chalk and Medway Clay were indispensable for its production. Later, however, it was considered that if a clay similar in chemical composition and physical condition could be obtained in other districts, and a suitable limestone was also available, true Portland cement could be manufactured. This suggestion soon took a practical form. The Boulder Clay overlying the Coal Measures of the Carboniferous system which occurs in the counties of Northumberland and Durham, notably on the banks of the Tyne, was found to be similar in composition to the alluvial deposits of the Medway, as the analyses of specimens Nos. 2 and 3 indicate. Moreover, it was ascertained that large quantities of Thames Chalk were being transported to the Tyne as ballast, at a very nominal freight, by sailing vessels known as "Colliers," of which the sole occupation was to carry coals from Newcastle and neighbouring ports to London. Another condition presented itself favourable to the manufacture of "Portland" in the north of England, in that the cost of fuel, an important item in the manufacture, was much lower in the north of England than on the Thames. These advantages, coupled with the fact that the scale of wages then prevailing was considerably lower in the north than that in the London district, tended to stimulate Portland cement making in the north of England, with the result that besides Thames makers establishing branch manufactories, many new enterprises were started on the Tyne, Wear, and other neighbouring districts, which prospered for a time,

notwithstanding the existing prejudice in favour of London-made Portland cement. Yet at one time so strong was this partiality towards London Cement that some engineers and architects stipulated in their specifications that the Portland cement to be used on the structures they were responsible for must be made from materials wrought and gotten on the Thames or Medway.

Unfortunately for the manufacturers of the north their prosperity was short-lived, for the following reasons. With the introduction of "screw steam colliers," a class of steamer designed and built by Sir Charles Palmer at his well-known shipyard at Jarrow-on-Tyne, all of which were fitted up with water-ballast appliances, the old-fashioned sailing "colliers" became a thing of the past. Also the great saving in fuel in the manufacture of cement by the introduction of improved systems and modern appliances cancelled the advantage of the manufacture being carried on in a coal-mining district. These factors, coupled with the levelling up of wages in the north through the influence of Trade Unions, all served to sweep away the anticipated economies of manufacture in the north, and the industry there is now in a state of decline, many works being closed.

The specimen of Boulder Clay from the glacial deposit of Redheugh is a good example of that variety of argillaceous rock which is suitable for Portland cement making. Redheugh is a district situated on the south bank of the Tyne, about two miles west of Gateshead. The deposit is fully thirty feet thick, and is a typical example of Boulder Clay. Frequently immense boulders are found embedded in the clay, and as these sometimes weigh several tons they are a serious impediment to the clay-diggers. Frequently fragments of coal are also met with in the digging, probably derived from the coal

measures, which are mined at Mickley and Prudhoe, villages a few miles further west from Gateshead. The Boulder Clay deposits at Redheugh are overlain by a bed of brick-earth of recent formation, averaging about ten feet in thickness. This is generally utilised for the manufacture of bricks for building.

Brief reference will now be made to the minor constituents present in the raw materials employed for the manufacture of Portland cement. It will be observed from the foregoing analysis of the Thames Chalk used that besides the $CaCO_3$ there are present Fe_2O_3 and MgO, but the proportions are so insignificant that they may be passed over without comment. The same compounds, however, occur in appreciable quantities both in the "Medway Mud" and in the Boulder Clay of the north of England.

The presence of ferric oxide in a moderate proportion is by no means detrimental to the quality of the finished cement. It has been found that it assists the complete chemical combination of the raw materials in calcination, especially if alumina is deficient in the clay. Fe_2O_3, however, in excess, is not desirable, as it affects the colour of the cement, giving the work constructed with it a rusty brown appearance after being exposed to the atmosphere, instead of the light greenish grey shade of colour of good Portland cement. Moreover, the iron compound is liable to be acted upon by the sulphur which is present in a small degree as calcium sulphate in most cements of the Portland type, being sometimes present in the clay, or in the fuel employed for the calcination, or it may be added after calcination, which operation will be referred to later.*

* See page 25.

The greenish-grey shade of colour dominant in true Portland cement is attributable to the presence of a small percentage of iron in the cement. Spasmodic attempts have been made to manufacture White Portland cement, but up to the present they have not met with the success that would justify the presence of a specimen in this collection. The measure adopted to obtain a white product is the exclusion of iron from the raw materials used in the manufacture, which is quite practicable. The amount of Fe_2O_3 in the chalk usually employed is, as has just been mentioned, so infinitesimal that it need not be taken into account. Clay, on the other hand, lacking iron in appreciable quantity, is more difficult to obtain, and is chiefly confined to kaolin, or decomposed felspar, better known as china clay.

Good sound Portland cement has been manufactured from chalk and kaolin, which, when set and hardened, was as white as plaster of Paris ; but the limited supply of kaolin in this country, and that only in districts far removed from where pure chalk or limestone can be easily obtained, does not recommend the manufacture, up to the present, as a sound commercial enterprise.

Most of the argillaceous rocks employed for Portland cement making contain a small proportion of magnesia, but it is generally admitted that if the quantity in the finished material does not exceed four per cent., no deterioration of the cement need be apprehended. Some experts maintain that it acts similarly to free lime and combines chemically with the silicates in the calcination. If such be the case, and MgO is ignored when the raw materials are proportioned, an overlimed cement may be the result, which will lead to disastrous consequences.

As the analyses of the raw materials indicate, the amounts of sulphur and sulphur compounds in the

Medway Clay are infinitesimal, and are lacking altogether in the Thames Chalk and the Boulder Clay of the north. The fuel employed for calcining, however, which is usually gas coke, contains a considerable amount of sulphur, which combines to a certain extent with the raw materials during calcination, and this accounts for the increased percentage of sulphur compound appearing in the analysis of the finished cement. It may here be stated that some manufacturers add a small quantity of calcium sulphate, in the form of gypsum, to their product after calcination, their object being to retard the initial indurating property of the finished material, a subject which will be referred to later.*

The alkalies present in most of the raw materials useful for making Portland cement are very insignificant in amount, and are, therefore, of little importance; indeed, some "cement chemists" do not think it worth while to determine their existence in their analyses. Others, however, assert that they are valuable constituents, and believe them to be useful transmitters of silicic acid to the lime, thereby accelerating the complete chemical combination in the calcining process. It will be noticed that there is quite a substantial percentage of alkalies in the clay from the Medway. Doubtless this is owing to the fact that it is a salt-water deposit.

Having now described the specimens representing the raw materials that are usually employed for the manufacture of Portland cement by what is known as the "wet method," it may be instructive to refer briefly to the proportions of the respective materials that are necessary for the making of a sound hydraulic cement of the Portland type, and the process of manufacture.

* See page 25.

Taken roughly, providing the chalk is as pure a carbonate of lime as the foregoing analysis indicates, and the clay contains about the same percentage of silica and alumina as shown in the two analyses, it was considered by the original makers that five parts by weight of chalk to two parts of clay was a suitable mixture. Since, however, the chemistry of Portland cement making has become a study and is now better understood, more accurate methods of procedure have been adopted. The exact proportioning is now dependent day by day, and in some cases hour by hour, on the result of the chemical analysis of the raw materials in the laboratory of the works, which has now come to be an indispensable part of the establishment of a well-conducted cement factory of the present day.

On examining the specimens and the details enumerated on the labels, the student will notice that the process of manufacture may be classed under three heads: first, the mechanical mixing of the raw materials preparatory to calcining; second, the process of calcination, producing what is known as "clinker"; and, lastly, the reduction of the calcined material to practically an impalpable powder.

No. 4. Thames Chalk and Tyneside Boulder Clay, mechanically mixed and dried.

No. 5. Thames Chalk and Medway Clay, mechanically mixed and dried.

The usual process adopted by the early exploiters of the manufacture is to mix in a circular tank, known as the wash-mill, the proper proportion of chalk and clay, diluted with five times their weight of water. In the tank are rotating harrows, which disintegrate the chalk

and clay, and reduce the mixture to the consistency of thin cream, which is known as "slurry." By the centrifugal agitating force of the harrows the thin mixture is forced through apertures in the walls of the circular tank, which are covered with fine wire gauze. The liquid is then pumped up into large shallow reservoirs, locally known as "backs," which in a fair-sized works cover an area of several acres, and there the slurry is allowed to remain until the solid material, at first in suspension, is precipitated, and the superincumbent water is driven off by evaporation and surface drainage. The plastic mixed material remaining is then conveyed by manual labour in wheel-barrows or small trucks to covered spaces, known locally as "drying flats," which are heated artificially from beneath, when the dried material, called "dried slip," or slurry, is ready for calcining.

In the year 1870, Wm. Goreham of Swanscombe, in Kent, secured a patent for an improved system of mechanically mixing chalk and clay for manufacturing Portland cement, which is known as Goreham's semi-wet or wet-grinding process. The same tank or wash-mill is employed as that previously described; into this the raw materials are thrown, but with only about a third of their weight of water. Instead of the exit apertures in the wash-mill being covered with fine wire gauze, metal gratings are substituted, through which the mixed chalk and clay pass in a condition resembling both in colour and consistency thin oatmeal porridge. This material is then passed through horizontal mill-stones, which reduce the material to a fine thin plastic semi-fluid condition. It is then conveyed by pumping or other mechanical means to the drying flats. The advantages accruing from this "wet grinding" system

over the old-fashioned "back" method must be obvious to the most casual observer. The immense area occupied by the "backs" is dispensed with, the time taken for the proper precipitation of the material in the backs, which often extended over several weeks, and sometimes months, in the winter, and the danger of the unequal settlement of the raw material owing to the different specific gravity of the chalk and clay, are obviated, and there is a saving in labour. All these advantages have contributed to the value of this improvement, and wet grinding is almost universally adopted where the wet method of manufacture is necessary.

No. 6. Thames Chalk and Medway Clay, Calcined, known as **Clinker.**

No. 7. Crushed Clinker.

The usual form of lime-kiln then in vogue was adopted for calcination by the inventor and early manufacturers of Portland cement, but when it was discovered that a much higher temperature was needed for the calcination of true Portland cement, a wide tapering chimney was added to the kiln, resembling in shape the neck of a bottle, hence the name "bottle kiln" applied at that period to describe the apparatus for calcining Portland cement.

The consumption of fuel in the calcination being an important item of expenditure in the cost of making Portland cement, fully half a ton of coke being needed in a bottle kiln to calcine one ton of cement, a multitude of improvements and patent kilns were from time to time introduced, many of which have had their day and since passed into oblivion. Others still survive, and among them may be mentioned the Dietsch and Schneider kilns

of Germany, the Aalborg kiln, a Danish invention, and the Johnson's patent chamber kiln, invented by I. C. Johnson, whose name appeared prominently in the historical notes. These, as well as many other improved kilns, still survive, and are adopted in all parts of the world, but by far the most radical change and improvement in the process of calcination of Portland cement has been the recent introduction of the rotary system of burning.

No. 8. Rotary Kiln Clinker.

The rotary kiln, sometimes known as the Ransome rotary kiln, was invented and patented in May, 1885, by Frederick Ransome, of London, who had given much of his time and attention to the uses and manufacture of cements.

Experimental kilns on Ransome's system were erected at several cement manufactories, but for various reasons, too numerous and intricate to elaborate in this brief description, they did not give the satisfaction anticipated, and eventually the system was pronounced a failure and the process was abandoned.

Several years later a firm of engineers in America were desirous of finding improved methods of manufacturing Portland cement, including the process of calcining, as the industry had assumed an important position in the United States. Doubtless profiting by information gathered relative to the previous experimental trials of the Ransome system of calcining in England, coupled with the details given in Ransome's specification, they invented and introduced a rotary kiln identical in most respects with Ransome's, but with minor alterations and improvements, which overcame the difficulties that had prevented the success of Ransome's original Rotary

system. This American innovation very soon earned a good reputation, and at the present time it commands an unrivalled position as an apparatus for the calcination of Portland cement, not only in America, but in England and all over the world where Portland cement is manufactured.

The rotary kiln may be described as a nearly horizontal iron or steel cylinder, varying from about eighty to one hundred and twenty feet long by about seven to eight feet in diameter, slightly inclined in position, and having a slow rotating motion, propelled by toothed gearing. It is lined with bricks, those at the end near the zone of combustion being necessarily of a very refractory nature. The mixed raw materials from the wet grinding mill are fed into it at the upper end. At the lower end a jet of incandescent fuel, propelled by a blast fan, is injected into the cylinder, the heated fumes from which are forced up the cylinder, driving off the moisture contained in the slurry flowing in at the upper end. The dried slurry then gradually travels downwards to the zone of combustion, being automatically impelled by the inclined position and revolving motion of the cylinder, and in passing through is calcined, and finally falls into a cooling chamber, similar in many respects, as regards form and rotary motion, to the calcining cylinder; after cooling the clinker, which is in a granular condition, is automatically conveyed to the grinding mills.

The specimen No. 8 is a good example of rotary kiln clinker. It will be manifest even to the casual observer, that physically it is in a much more suitable condition to undergo the process of grinding than even the mechanically crushed clinker from the intermittent fixed kiln. Moreover, it is also obvious that the risk of there

being any underburnt or uncombined ingredients in the small granular "rotary" particles is less than with the large masses of clinker which are drawn from the old-fashioned kilns.

The original methods of calcining with the "Bottle" or with Johnson's Chamber Kiln, being intermittent processes, occupied at least two weeks, when cooling, drawing, and re-loading were taken into consideration. The Rotary process, on the other hand, being continuous, can easily be accomplished in as many hours.

It may, however, be mentioned that Portland cement calcined by the Rotary process is almost invariably of a very quick-setting nature, in that the hardening action of the finished material when hydrated commences almost immediately. This is accounted for chiefly by the fact that there is generally an entire absence of sulphur compounds in the clinker produced by the Rotary process, owing to the calcination being accomplished by a jet of flame generated outside the kiln, whereas in the old-fashioned vertical kilns the clinker absorbs a certain amount of sulphates contained in the coke or other solid fuel present inside the kiln itself.

There are several methods adapted to counteract this quick-setting property at the disposal of the manufacturer. It is sometimes accomplished by aerating or hydrating the clinker before grinding or by aerating the finished cement. Another method is to introduce a jet of steam into the grinding mill during pulverization, which enables every particle of the material to absorb and combine with a regulated quantity of condensed steam or water, which is practically another form of hydration. The usual method at present adopted, and certainly the easiest, is by the addition of a small percentage of sulphate of lime in the form of gypsum or

plaster of Paris, which is incorporated with the cement in the process of grinding. Some manufacturers, however, object to this last-named method, because unless the addition of $CaSO_4$ is very carefully proportioned, and equally and thoroughly incorporated in the grinding process, it becomes a highly dangerous supplement. The sulphur compounds are then liable to combine with the iron and other compounds in the cement, causing expansion of the whole mass. Again it is stated by some authorities that the slowing effect produced by the addition of sulphate of lime sometimes passes off when the cement is stored. The reason why the action of sulphate of lime should have the effect of retarding the initial set of Portland cement seems, up to the present, to be a matter of debate among cement manufacturers and experts, and a scientific elucidation would be welcome.

The time of setting, in a carefully prepared cement, can now be easily controlled by the works chemist in proportioning the respective percentages of the raw materials. It is an established fact, well-known to all cement makers, that a highly clayed mixture produces a quick setting cement, while on the other hand, an extra percentage of carbonate of lime in the mixture retards the setting of the finished material, therefore it seems more legitimate to control the setting property of a cement at the source of the manufacture, rather than to add a foreign material later on, which may prove to be a dangerous adulteration if not treated with great care.

This may be an opportune moment to tabulate a few facts as to the hardening properties of Portland cement, popularly termed "setting."

In the opening remarks of these notes on the manu-

facture of Portland cement it was stated that the resultant product of raw materials, after calcination and subsequent grinding, is, roughly speaking, a double silicate of lime and alumina. The percentage of each base and acid present can easily be ascertained by chemical analysis, details of which have been given, but there seem to be differences of opinion and uncertainty with regard to the nature and the amount of the compounds formed from these acids and bases, and the precise mechanism of the process of setting is still in doubt. Some writers attribute the setting, first to the presence of the calcium aluminates, by their hydration and subsequent crystallization, followed by a slower hydration and crystallization of the calcium silicates. First, very minute crystals cover the grains, which gradually extend and interlock, thus forming a coherent mass, and this constitutes the setting properties of Portland cement.

The primary crystallization just referred to is known as the initial set, and the latter as the final set. The former is the period when the hardening process begins, warning the manipulator that crystallization has commenced, and that disturbance of the still apparently plastic material will be detrimental to the setting. This can easily be detected by the operator in that the semi-fluid or mobile consistency of the mass disappears, and it assumes a dull solid appearance, although quite soft if the slightest pressure is applied to the surface.

The period of final set is the time that the plastic cement mixture takes to become sufficiently indurated to resist a specified pressure without leaving any indentation. There are divers methods and forms of apparatus at present in use by which to determine the period of ultimate or hard setting, superseding the original facile,

although crude, method adopted by the pioneers of the manufacture, that of the application of the finger or thumb nail. The numerous mechanical appliances need not be described here, suffice it to say that the Vicat needle apparatus is one that is in very general use.

The Vicat needle apparatus consists of a frame supporting a movable rod with a needle attached to the lower end, the point of the needle usually being 1 mm. =.039 inch. The rod carries an indicator, which moves over a graduated scale attached to the frame. Under the movable or suspended rod, resting on the base of the frame, is a small cylindrical mould, into which the plastic cement to be tested for its setting properties is placed. The needle is then brought gently into contact with the surface of the cement, and the weight of the plunger and needle, combined with that of a small disc placed at the top of the plunger or rod, causes the needle to penetrate the plastic cement. If the needle pierces the pat of cement completely through to the base of the mould, the cement has not commenced to set, but if it ceases to penetrate to the bottom of the pat the initial set has taken place. The same process of penetration is again carried out, and if the needle then fails to make an impression on the surface of the pat, the cement is considered to be finally set.

An apparatus invented by C. H. Watson, which places the Vicat needle test on a quantitative basis, has recently been introduced with satisfactory results.

No. 9. Finished Portland Cement, Ordinary Grinding.

No. 10. Residue from No. 9.

No. 11. Finished Portland Cement, Fine Grinding.

No. 12. Residue from No. 11.

The last stage in the process of Portland cement manufacture, that of reducing or grinding into a fine powder, has undergone revolutions since the introduction of the cement, equally as startling as that of calcination.

Originally the masses of clinker as they came from the kiln were reduced to a coarse granular form, either by hammers and manual labour, or by some type of crusher or stone breaker. The crushed material was then passed through horizontal millstones of the French burr type, and thence conveyed to a series of sieves, the coarse residue retained on the sieves being sent back to the millstones to be re-ground.

This method of grinding held sway for many years with slight modifications. Some manufacturers, notably in the north of England, introduced the use of millstones made from rock emery. The advantage claimed was that the emery millstone did not require "dressing," an operation both laborious and expensive when French burr stones are employed

When the roller system of flour milling supplanted the now antiquated millstone method of grinding wheat, the same system was attempted by manufacturers of Portland cement, but it did not meet with the success that was anticipated, and was abandoned. Other grinding appliances, however, quickly followed, including Ball Mills and Tube Mills, either of these, and sometimes both, at first supplementing the millstone grinding, and later superseding them. The Ball Mill is an iron cylinder or drum, divided internally into segments with

inclined steps. The interior is partially filled with steel balls of various dimensions along with the cement clinker. The cylinder revolves, and the rotating motion causes the balls to ascend, and at a certain angle to fall by gravitation as a cascade. The continual movements and the attrition of the balls reduces the cement to a powder, which is then automatically sifted by a series of sieves that line the walls of the cylinder.

The Tube Mill resembles the Ball Mill somewhat in its application, in that the clinker or coarse cement is reduced to a very fine powder by the pounding action of steel balls. In the case of Tube Mills, however, there is no sifting, the mill is placed in a perfectly horizontal position, and the coarse material travels through it to the outlet by gravitation, being thoroughly ground to a fine powder in transit. It may be mentioned that many users of the Tube Mills prefer flint pebbles to steel balls for pounding. The spherical flint pebbles are chiefly obtained from the north coast of France, being the flint nodules washed out of the Upper Chalk exposed on the coast of that region.

In reference to the foregoing specimens, the fact should be mentioned that, other conditions being equal, Portland cement which is finely ground is the more valuable. In most cases the cement is used with an admixture of sand or other aggregate, and an impalpable powder when mixed with water will be more capable of surrounding each particle of the aggregate with a coating of cement than if the cement itself contained coarse grains.

In testing Portland cement to ascertain the degree of fineness it is important that the sieve be accurately made, not only as regards the number of holes per square inch, but as to the thickness of the wire for making it.

Roughly speaking, the usual standard followed in this country is that the diameter of the wire must be half the width of the hole, i.e. a sieve having 5800 holes (or to be more accurate, 5776 holes) per square inch, must be made of wire having a diameter of ·0044 of an inch, thus leaving a space between each wire of ·0087 of an inch.

To illustrate the effect of fine grinding on the strength of Portland cement, a few particulars will be given extracted from a standard modern text-book.* The finished cement as it was received from the manufacturer was again ground for various periods in a Ball Mill, and then mixed with three parts of standard sand. The following tensile strengths were obtained from test briquettes 28 days old:—

Cement as received ..	242·7	lbs. per square inch.
Ditto, ground for 2 hours	294·4	,,
Ditto, ground for 5 hours	350·5	,,
Ditto, ground for 14 hours	380·6	,,

The increase in strength is manifest, but it must be remembered that the extra grinding increases the cost of manufacture, and very fine grinding may be prosecuted beyond the limits of practical efficiency combined with economy.

It may be mentioned that since the specimens of finished Portland cement were presented to this Museum the different stipulated grades of fineness have been revised, and the British standard specification now provides that the residue on a sieve having 5776 meshes per square inch must not exceed 3 per cent., and the residue on a sieve having 32,400 meshes per square inch must not exceed 18 per cent.

Some experts forecast that in the near future a sieve

* C. H. Desch, *The Chemistry and Testing of Cement*, p. 135.

having 100,000 meshes per square inch will be in general use in Portland cement manufacture.

There are a multitude of appliances besides those already mentioned employed for the treatment of the raw material, calcining, and finishing of Portland cement, far too numerous even to summarise in these brief notes. Suffice it to say that, although the initial cost of introducing up-to-date appliances and erecting modern machinery for the manufacture may exceed that of the old-fashioned plant employed by the early exploiters of the industry, the saving in space, time, and labour is very great, and the superiority of the finished article beyond comparison. In fact, to quote the words of a recent writer who has given much thought to investigating the chemistry and the development of the industry, "The whole process of manufacture has been brought to very nearly that ideal state of industry where the man is put into his proper place of supervision, and is not used as a sentient machine."*

SPECIMENS 13–22, illustrating the raw materials, process of manufacture (dry method), and finished cement, manufactured from Lias Limestone and Shale.

Presented by Messrs. Chas. Nelson & Co., Ltd., Stockton, Rugby.

No. 13. Blue Lias Limestone, STOCKTON QUARRIES, WARWICKSHIRE.

Chemical Composition.

$CaCO_3$ 76·27, SiO_2 13·31, Al_2O_3 4·09, Fe_2O_3 2·90, MgO 1·72, Alkalies and loss 1·61 = 100·00.

* E. Blount, "Recent Progress of Portland Cement Industry," *Jour. Chem. Industry*, 1906, Vol. XXV., p. 1022.

No. 14. Shale, STOCKTON QUARRIES, WARWICKSHIRE.

Chemical Composition.

$CaCO_3$ 40·88, SiO_2 30·05, Al_2O_3 3·35, Fe_2O_3 10·70, MgO 3·68, Alkalies and loss 5·34 = 100·00.

No. 15. Lias Limestone and Shale, ground and mixed in suitable proportions.

No. 16. "Shammock," a local term given to the above-named raw materials when ground and mixed and pressed into bricks ready for calcining.

No. 17. Mixture of Lias Limestone and Shale after Calcination, known as **Clinker.**

No. 18. Clinker crushed preparatory to grinding.

No. 19. Finished Cement, Ordinary Grinding, ground to a fineness that leaves a residue of not more than 10 per cent. on a sieve having 5800 meshes per square inch.

Chemical Composition.

CaO 61·54, SiO_2 19·20, Al_2O_3 8·32, Fe_2O_3 3·50, MgO 2·25, SO_2 1·68, CO_2 and H_2O 1·38, Insoluble residue 0·54, Alkalies and loss 1·59=100·00.

No. 20. Residue from Finished Cement, Ordinary Grinding.

No. 21. Finished Cement, Fine Grinding, ground to a fineness that leaves a residue of not more than 10 per cent. on a sieve having 32,000 meshes per square inch.

No. 22. Residue from Finished Cement, Fine Grinding.

As the chemistry of Portland cement came to be studied, and consequently better understood, it was found that other forms of carbonate of lime and silicate of alumina than Chalk and clay might be used for the manufacture with advantage.

The base of the Lower Lias deposits of the Jurassic system occurring in the Midland Counties usually consists of alternating thin-bedded limestone and shale. These beds were considered to be suitable for Portland cement-making, providing the process of manufacture could be adapted to the composition of these rocks. This has been accomplished, as the details just enumerated demonstrate.

Both these rocks, it need hardly be pointed out, differ widely in physical character from Chalk and clay, being very much harder. A different process had therefore to be adopted in the reduction and mixing. They are treated by what is known as the "dry method," in that after being thoroughly dried they are reduced to a fine powder. The rocks are then mixed in specific proportions depending on the chemical composition of the various batches about to be treated. The powdered mixed material is then moulded into bricks under pressure, which are then ready for calcination. It should, however, be mentioned that when the Rotary system of calcination, which has already been described, is employed, the pulverised material is conveyed direct to the Rotary Kiln without being subjected to the moulding process.

The chemical composition of the two rocks is very variable, and the analyses often differ considerably from those given above under the head of each rock. There are fully fifty seams in the Stockton quarries, those of the limestone varying in thickness from a few inches up to

two feet, between which are intercalated seams of shale. The limestone seams in these quarries vary in $CaCO_3$ from 80 per cent. to, in some cases, as low as 68 per cent.; SiO_2 varies from 23 per cent. to 16 per cent.; Al_2O_3 from 8 per cent. to 7 per cent.; Fe_2O_3 from 2 per cent. to 3 per cent.; MgO from 1 per cent. to 3·5 per cent.; and SO_3 from a trace to nearly 2 per cent. The layers of shale, which usually exceed the limestone in thickness, show an analysis of about 30 per cent. of SiO_2; 12·5 per cent. of Al_2O_3; 4·7 per cent. of Fe_2O_3; 49 per cent. of $CaCO_3$; 4 per cent. of MgO, with a trace of SO_3. Great care has therefore to be exercised in proportioning these raw materials in the preliminary process of manufacture.

The subsequent treatment of the mixed material to produce finished cement is identical with that described in the manufacture when chalk and clay are employed, and therefore need not be described again.

SPECIMENS 23–32, illustrating the raw materials, process of manufacture (dry method), and finished cement, from Chalk Marl.

Presented by the Saxon Cement Co., Ltd., Cambridge.

No. 23. Chalk Marl, SAXON QUARRIES, NEAR CAMBRIDGE.

No. 24. Chalk Marl, dried previous to grinding.

No. 25. Chalk Marl, ground and mixed in proper proportions.

Chemical Composition.

$CaCO_3$ 76·60, SiO_2 15·72, Al_2O_3 4·20, Fe_2O_3 1·89, $MgCO_3$ 1·31, loss 0·28=100·00.

No. 26. Mixed Chalk Marl, pressed into bricks preparatory to calcining.

No. 27. **Clinker,** being mixed Chalk Marl after calcination.

No. 28. **Crushed Clinker,** ready for grinding.

No. 29. **Finished Cement, Ordinary Grinding,** ground to a fineness that leaves not more than 10 per cent. residue on a sieve having 5800 meshes per square inch.

Chemical Composition.

CaO 63·04, SiO_2 21·04, Al_2O_3 5·42, Fe_2O_3 4·50 MgO 0·99, SO_3 1·81, Insoluble matter, alkalies etc., 3·20=100·00.

No. 30. **Residue from Finished Cement, Ordinary Grinding.**

No. 31. **Finished Cement, Fine Grinding,** ground to a fineness that leaves not more than 10 per cent. residue on a sieve having 32,000 meshes per square inch.

No. 32. **Residue from Finished Cement, Fine Grinding.**

Since the time of Smeaton, which, as the foregoing Historical Notes indicate, was long before the introduction of Portland cement,* spasmodic attempts have from time to time been made, both in this country and abroad, to manufacture a reliable hydraulic cement from those natural rocks which are made up of various component parts of lime, silica, and alumina, just as they occur in nature, without any subsequent mixture after quarrying. The advent of Portland cement temporarily discouraged these efforts. With the growth, however,

* See page 2.

of engineering projects during the first half of the nineteenth century, calling for maritime constructions on a gigantic scale both of a defensive and pacific character, a great demand for hydraulic cement arose which stimulated the endeavours not only of the pioneers of Portland cement, but also of those who sought to make cement from the rocks containing naturally suitable proportions of calcium carbonate and clay. Notwithstanding the acknowledged superiority of true Portland cement over that manufactured from these natural deposits, the demand for all kinds of hydraulic cement was so great that the production of the variety in question grew apace, notably in Belgium and Germany, and still continues, the finished product being known as "Natural Cement." There are also several varieties of Natural Cement produced in the United States of America; among them may be mentioned Rosendale and Louisville Cements, named after the districts where the natural rocks are situated and quarried for cement-making.

The manufacture of Natural Cement has found little favour in the British Isles, with perhaps the exception of Roman Cement, which will be referred to later,* therefore other specimens of Natural Cement do not appear in this collection.

Since, however, the chemistry of Portland cement making has become a study, and the manufacture has been carried out on more scientific lines, some of these natural rocks, the component parts of which do not vary to any considerable extent as the quarrying proceeds, have been successfully employed for the manufacture of true Portland Cement.

The Chalk Marl of Cambridgeshire, underlying the

* See page 102.

Chalk beds of that county, and resting on the Cambridge Greensand, is a notable instance.

By constant laboratory examination and regular chemical analyses, the proper proportion of calcium carbonate and silicate of alumina can be controlled by the careful admixture of several batches of the raw material previous to calcining, and a thoroughly reliable Portland cement can be produced. The process of manufacture is by the dry method, and practically identical with that adopted where the Lias deposits are employed, which has already been described; it is therefore not necessary to refer in detail to the foregoing specimens illustrating the process of manufacture of "Portland" from Chalk Marl; suffice it to call the attention of the student to the specimens Nos. 6, 17 and 27, clinker produced from Chalk and Clay, Lias Limestone and Shale, and Chalk Marl; they are identical in colour and density; and the finished products, Nos. 9, 19 and 29, are also exactly similar in colour and general appearance. Moreover, the component parts set forth in the respective analyses are almost alike.

Such, then, is a brief description of the typical specimens representing the raw materials, the various methods of manufacture, and the finished product, of Portland cement at present manufactured in this country.

There are many and various rocks besides those already mentioned forming the crust of the earth in different regions of the civilised world, composed of suitable basic and acid compounds, which are now being utilised for the manufacture of Portland cement in the respective localities where they occur; but as this collection is intended to include only cements of British manufacture,

specimens of those made abroad, and the raw materials from which they are manufactured, are not included. It is hoped, however, that the day is not far distant when sufficient space will be allocated in the economic section of the Sedgwick Museum to admit at least specimens of the raw materials which are being employed for the manufacture in the Overseas Dominions of the British Empire; because since the opening of the present century extraordinary developments of the industry have occurred in those Dominions and in India, and continue to extend, notably in Australia, Canada, Jamaica, the Malay States, New Zealand, and South Africa; and it is believed that in every corner of the civilised world there are deposits of raw materials ready to hand suitable for the manufacture, if scientific knowledge, coupled with enterprise, were brought to bear on the question in districts as yet unexplored with that purpose in view.

Here, then, there is a limitless field of research for the student of practical geology, not to mention the student of applied chemistry, in the further development of an industry, which, although already of gigantic proportions, is believed by some who are competent to judge, to be still in its infancy.

It may interest the Irish students of this University to record that quite recently, since the specimens under review were placed in the Museum, and the foregoing notes compiled, the industry of Portland cement making has taken a practical form in the north of Ireland.

Rocks belonging to the Senonian or Upper Chalk of the Cretaceous system underlie the basaltic plateaux that cover nearly the whole of county Antrim. These calcareous deposits appear as a fringe around the basaltic lava, and yield a stone which is known in geological nomenclature as "Senonian Chalk," and commercially

as "White Limestone." This rock has been found to be a useful base for the manufacture of Portland cement.

Fortunately there are extensive beds of marine clays of post-glacial date lying immediately above the red marls of the Keuper series, which fringe the south-east coast of Co. Antrim, and which are in close proximity to the Senonian Chalk deposits. A cement factory has just been erected close to Magheramorne, a station on the Belfast and Carrickfergus Railway, a few miles south of Larne, where an unlimited quantity of both these raw materials is available, and it is stated that there are prospects of the Irish Portland cement competing successfully with the cement which has previously been imported into that district from the Thames. The raw materials are treated by the "wet method" ; and as the process of manufacture and the resultant finished cement are exactly similar to those on the Thames, it would not serve any useful purpose to include specimens in the collection.

It may be useful to record here a few facts in relation to at least two materials besides those that have been described, which, although not natural products of the earth, and therefore not strictly associated with the science of geology, are being tentatively employed for the manufacture of Portland cement in this country. The utilisation of these materials, both of which are residual products, is, however, still in an initial or experimental stage, therefore specimens of the ingredients about to be described, or the finished cement produced from them, do not at present appear in the collection.

The first is a material known as "Tank Waste," a residual product from the manufacture of alkali; and it may be interesting if an attempt be made to give a

brief description of the process of alkali manufacture, which will demonstrate how this residual or waste material is produced.

The first process in the manufacture of alkali, by what is known as the Leblanc process, invented by Nicolas Leblanc about 1790, is the decomposition of sodium chloride, NaCl (common salt), by means of sulphuric acid (H_2SO_4), by which sodium sulphate (Na_2SO_4) and hydrochloric acid (HCl) are produced, the former being known commercially as "salt cake." This ingredient is next heated or fluxed with calcium carbonate ($CaCO_3$), in the form of chalk or limestone, together with small coal, forming sodium carbonate (Na_2CO_3) and calcium sulphide (CaS). The separation of these two salts is easily accomplished by lixiviation, or dissolving the former out with water, from which the soda-ash of commerce is obtained, leaving the insoluble material popularly distinguished as "tank" or "alkali waste." The following is a typical analysis of this material, which is generally considered to be of no value, and is cast aside, forming the unsightly miniature mountains which usually disfigure the landscape in the neighbourhood of chemical works:

*Chemical Composition of Tank Waste.**

$CaCO_3$ 38·81, CaS 35·12, Na_2CO_3 1·63, $Ca(OH)_2$ 9·53, CaS_2O_3 1·49, Coal 6·27, Al_2O_3 0·13, FeS 2·76, SiO_2 1·21, Sand 2·61=99·56.

It will be seen by the above analysis that although $CaCO_3$ dominates there is a considerable quantity of CaS present in tank waste, which naturally seems to condemn it for the manufacture of Portland cement, remembering

* Blount and Bloxham, *Chemistry for Engineers and Manufacturers*, p. 37.

that in the foregoing notes it has been repeatedly emphasised that anything above a small percentage of sulphur in any form is a dangerous ingredient in Portland cement. Notwithstanding this, spasmodic attempts have been made from time to time to introduce tank waste as a raw material in the manufacture, not necessarily substituting it entirely for the chalk or limestone employed as the basic oxide of the manufacture, but supplementing them by adding a certain proportion of tank waste to the mixture in the wash-mill where the wet method of manufacture was in vogue, presuming that a small percentage of calcium sulphide would not be detrimental, especially when it has been acknowledged from early times that the presence of sulphur, in some form or other, in a small degree rather improved than reduced the quality of the finished material. The chemical composition of tank waste, however, was found to vary to such an extent from day to day that many cement manufacturers refused to use it, and in course of time its employment was practically abandoned.

Circumstances, however, have since arisen which put a more favourable complexion on the utilisation of tank waste for cement making. A treatment known as the Claus-Chance process has been introduced in the manufacture of alkali, whereby the sulphur present in the tank waste can be almost entirely eliminated, the recovered sulphur at the same time becoming a valuable asset in the manufacture of alkali. The residue of this new process, a semi-fluid material, known locally as "Chance Mud," is said to be sufficiently free from sulphur to admit of its use as a raw material for Portland cement manufacture.

Chemical Composition of Chance Mud.

CaO 48·29, CO_2 39·60, SiO_2 1·98, Al_2O_3 1·38, MgO 1·51, H_2SO_4 1·26, K_2O 0·35, Na_2O 0·29, H_2O and organic matter 3·80=98·46.

The above analysis of the residue from the Claus-Chance process indicates that the proportion of sulphur which appears in the form of H_2SO_4 is insignificant, and it may be interesting to occupy a line or two in briefly describing the Claus-Chance sulphur recovery process.

The moist tank waste remaining as a sediment in the lixiviating process, previously referred to, is conveyed to vertical cylindrical metal towers, where it is subjected to the action of gases evolved from the calcination of limestone, whereby the calcium sulphide is converted into calcium carbonate. The sulphur is set free, mixes with the air, and issues as sulphuretted hydrogen. More air is admitted, containing sufficient oxygen for the combustion of the hydrogen, and the mixture is passed through red-hot iron oxide (burnt pyrites), which by its catalytic action causes the reaction $H_2S+O=H_2O+S$ to take place, and by cooling the vapour the sulphur is condensed in a pure form.*

The calcium carbonate left in the iron towers is in a semi-liquid form, which is known as "Chance Mud," and those interested in the use of this waste material feel sure of its value for the manufacture of Portland cement.

There are, however, obstacles to be overcome before this "mud" can be pronounced suitable, commercially, as a raw material for the manufacture of cement; for instance, the fluid nature of its composition makes it almost a necessity for it to be employed for cement

* G. Lunge, "Alkali Manufacture," *Encycl. Brit.*, 11th ed., Vol. I., p. 682.

making on the premises of the chemical manufactory, which may not be convenient. This and other objections, however, may be overcome, and the exploiters of this waste material for cement making are sanguine of ultimate success.

The other ingredient, of which there is practically an unlimited supply in this country, and which bears a certain analogy to the Tank waste or Chance mud just mentioned in that it is up to the present almost entirely a waste material, is the residual product of the manufacture of pig iron, and is known commercially as Blast-Furnace Slag. Before referring to some of the numerous attempts to introduce this material into the manufacture of cement of the Portland type, it may be instructive to describe, as briefly as possible, the manufacture of iron, and the consequent production of slag.

The student need hardly be reminded that iron is seldom, indeed never in appreciable quantities, found in nature in a pure state, but as an ore composed of a combination of metallic iron and calcareous, argillaceous and siliceous impurities. The aim of the iron-master is to separate these non-metallic substances from the iron, and he introduces a specific proportion of carbonate of lime into his smelting furnace, with the result that the clayey constituents and the silica combine chemically with the lime and set free the iron.

It will thus be seen that a chemical action takes place in the blast furnace similar to that which occurs in the calcining kiln of Portland cement, as already explained, the lime and clay combining chemically in each case. In order, however, effectually to disassociate the iron from the combined non-metallic impurities, a temperature sufficient to fuse completely both the iron and the combined basic and acid compounds is required; and

that the slag may possess the necessary fluidity, the lime must bear a certain ratio to the silica and alumina, which vary in a greater or less degree, and a proper addition of lime must be made, thus combining and carrying off all the silicate and alumina and forming a calcium alumino-silicate. The two constituents, molten iron, and fused clinker or slag, then gradually flow down the smelting furnace and accumulate in the lower part of the furnace known as the hearth. The molten slag, being of a lighter specific gravity than the molten iron, floats on the top, and they are both drawn from the furnace as molten streams at different levels.

Such is a crude attempt to describe briefly the process of iron manufacture, but it is hoped that it is sufficiently lucid to prove to the student that the fused slag bears a striking analogy to the over-calcined clinker of a Portland cement kiln, in that they are both chemical combinations of lime and silicate of alumina. The difference, however, between slag and normally calcined cement clinker is that the former has not only passed the stage of incipient fusion and complete vitrification, but has become fused into a molten liquid, whereas the latter is permitted to arrive only at the state of semi-vitrification or incipient fusion.

The question now arises, why does over-burned clinker, when reduced to powder and hydrated, not harden, whether it is produced in a cement kiln or in a blast furnace? This, again, opens the interesting and somewhat complex problem as to the cause of induration, more commonly called "setting," of cements of the Portland type. It has already been cited that unfortunately chemists are not all agreed as to the *modus operandi* of the setting of Portland and other cements of a similar type. Briefly, however, as previously stated, the

setting of Portland cement is a process of hydration and subsequent crystallisation. Now why this power of hydration and crystallisation is destroyed when the clinker is practically fused has not yet been fully explained. Some authorities are of opinion that the destruction of the setting property in overburnt Portland cement clinker may be connected with some difference in the state of solid solution in which the essential constituents are believed to exist, but they admit that sufficient knowledge on this subject has not been acquired up to the present to enable anyone to give a definite explanation.

The problem presents itself, is it possible or practicable to restore the overburnt clinker in a cement kiln, or the molten slag in a blast furnace, into a condition in which, when ground and water added, hydration and subsequent crystallisation will take place? This has been attempted with blast furnace slag, and with partial success, as the following facts will disclose.

Some years ago Charles Wood, of Middlesborough, discovered that if molten slag were plunged into cold water it immediately expanded enormously and was transformed into innumerable small particles. These, after the water evaporated, again partially combined and formed a vesicular, pumice-like mass, which, being very friable after drying, could easily be reduced to a fairly fine powder. This. Wood called granulated slag or "Slag Sand," and he employed it for manufacturing building bricks by the application of hydraulic pressure.

It may be mentioned that Wood's primary object in converting molten slag into granulated slag was to expedite the removal and transport of the material. As the molten slag was of no commercial value, the usual procedure in vogue when Wood introduced the system

of granulation was to collect it in iron wagons as it flowed from the aperture at the base of the blast furnace, called the "cinder notch," and thence transport it to some vacant ground to be deposited; or to discharge it into sea-going craft to be finally deposited at the bottom of the sea. But neither of these contrivances to get rid of this waste material could be accomplished until the molten slag had consolidated and been thoroughly cooled, a process which frequently occupied a considerable time.

Later it was discovered that Wood's slag sand, if further reduced to a fine powder, developed hydraulic properties if used as a mortar; and still more recently it was found that if a specific proportion of hydrated lime, which in itself is an impalpable powder, were incorporated with it, the mixture had valuable cementing qualities combined with hydraulicity. This manipulation has long since passed the experimental stage, and is being largely adopted in Germany and America. Several patents have been taken out to manufacture this cement by different methods, notably in Germany, and the finished material is sold generally under the name of "Slag Cement." Up to the present the manufacture has not found favour in the British Isles, therefore specimens of Slag Cement do not appear in the collection.

It may be mentioned that the process of granulation serves to eliminate the sulphur which is always present in a greater or less degree in blast-furnace slag. During ebullition the sulphur in the slag unites with the hydrogen in the water and passes into the air in the form of sulphuretted hydrogen. Some uncertainty seems to exist as to the reason why the slag by rapid cooling or chilling should become possessed of a property of

setting and hydraulicity. Some are of opinion that the fierce ebullition which takes place not only causes a physical change, but that a chemical action is also set up, thus altering the slag from an inert material to an active hydraulic cement. Others, on the other hand, assert that no chemical change takes place, and to prove their theory they have produced cement equal, if not superior, in quality to that manufactured from slag sand by simply mixing very finely ground blast-furnace slag with lime. The relation between true Portland cement and cement made from the residual product of blast furnaces is very curious, and cannot be discussed with advantage at the present stage; but that there is a singularly close analogy between them is evident.

Several methods of Slag Cement manufacture have recently been inaugurated in the iron districts of Scotland, and the cement sought to be sold as "Portland," but they are still in an initial stage, and not so far advanced as to warrant the introduction of examples of the process, or of the finished cement, into this collection; and as the Slag Cement industry is at present practically confined to Germany and America, specimens of it are not exhibited. The foregoing facts, however, tend to show that the barrier which separates what is at present acknowledged to be true Portland Cement, and that known as Slag Cement, is exceedingly slender; but although the pioneers of the latter confidently assert that they are prepared to prove the excellence of their new manufacture, up to the present evidence does not seem to be forthcoming to justify the material being classed as true Portland Cement. It is, however, the opinion of some that sooner or later the deficiencies and prevailing prejudices will be overcome, and that a cement equal in every respect, if not superior, to "Portland" will be produced from blast

furnace slag. This interesting problem seems to be well worthy of the careful attention and investigation of the student of economic geology and chemistry.

It is estimated that from sixty to seventy million tons of iron are made annually throughout the world, and an average of one and a half tons of slag is produced per ton of iron manufactured. This huge pile of waste material, less a negligible fraction which is used for road repairing and similar purposes, has to be cast away somewhere at a vast expense. The person who can turn this waste product to a useful purpose will be a benefactor to this and future generations. But when the time comes for the consummation of this aspiration it is to be hoped that the fortunate discoverer will not seek to affiliate his new invention with that of Portland cement and thus deck his new material with borrowed plumes. Let him have the courage to call it by a name that will disclose the source from which the cement came. If the quality is superior, or even equal to the established "Portland," why should he fear to divulge its origin?

Apology may be due to the reader of this descriptive catalogue for the space occupied in discussing the possible uses of waste material sought to be introduced into the manufacture of Portland cement, specimens of which are not included in this collection. Bearing in mind, however, that one of the chief objects in view is to interest the student of economic geology and allied branches of natural science, in possible, if not probable changes in the process of manufacture, and the employment of new raw materials in the making of cement, the present digression is perhaps justifiable.

It may be mentioned in this connection that some workers even now advocate the process of manufacture of true Portland cement by reducing the raw materials

employed into a fused molten condition in a blast furnace specially constructed for the purpose. Dr. Michaelis, of Berlin, several years ago succeeded in completely fusing the raw materials by a method which produced a Portland cement perfectly sound and satisfactory in every particular, but it is believed that his operations did not extend beyond the experimental stage.

Another author, who has made the chemistry of cement making a life study, forecasts an epoch when the raw materials will be hurled into a blast furnace by the truck load, dispensing with any preliminary process of washing, wet grinding, mixing, or drying, the resultant product being tapped out at the bottom as molten Portland cement clinker.*

Testing of Portland Cement

Specimens 33–45 illustrating progressive increase of tensile strength with age.

Presented by Messrs. I. C. Johnson & Co., Ltd., London.

No. 33. Illustration of testing apparatus.

No. 34. Test briquettes of cement, 1-inch section, ready for testing.

No. 35. Cement briquettes, 7 days old, broken at an average tensile strain of 430 lbs. per square inch.

No. 36. Cement briquettes, 28 days old, broken at an average tensile strain of 555 lbs. per square inch.

* B. Blount, "Recent Progress in Cement Industry," *Journ. Soc. Chem. Industry*, 1906, Vol. XXV., p. 1027.

No. 37. **Cement briquettes, 3 months old,** broken at an average tensile strain of 650 lbs. per square inch.

No. 38. **Cement briquettes, 6 months old,** broken at an average tensile strain of 800 lbs. per square inch.

No. 39. **Cement briquettes, 12 months old,** broken at an average tensile strain of 1250 lbs. per square inch.

No. 40. **Concrete briquettes,** composed of three parts of standard sand and one part of cement, ready for testing.

No. 41. **Concrete briquettes,** composed of three parts of standard sand and one part of cement, **7 days old,** broken at an average tensile strain of 140 lbs. per square inch.

No. 42. **Concrete briquettes,** composed of three parts of standard sand and one part of cement, **28 days old,** broken at an average tensile strain of 225 lbs. per square inch.

No. 43. **Concrete briquettes**, composed of three parts of standard sand and one part of cement, **3 months old,** broken at an average tensile strain of 400 lbs. per square inch.

No. 44. **Concrete briquettes,** composed of three parts of standard sand and one part of cement, **6 months old,** broken at an average tensile strain of 500 lbs. per square inch.

No. 45. **Concrete briquettes,** composed of three parts of standard sand and one part of cement, **12 months old,** broken at an average tensile strain of 550 lbs. per square inch.

A manufactured material, intended especially for structural purposes, and produced from natural rocks which are known to vary petrologically, as well as chemically, in the same rock-bed, and frequently in the same quarry, ought to be subjected to rigid tests before being used, in order to prove to the consumer that the material is sound and in every way suitable for the purpose intended. This mode of procedure is particularly essential in relation to cements. In timber, and even natural stone, defects are frequently apparent to the practical observer, before the material is handled by the builder; but the quality of cements, especially of the Portland type, cannot be diagnosed, even by an expert practitioner, when it is delivered to the consumer, and a iguarantee ought to accompany the delivery setting forth ts condition and genuineness. These and other similar reasons prompted the engineers of the French Government, who, as previously mentioned,* were the first public body to use Portland cement, to establish a standard specification of tests, containing conditions which the manufacturers were bound to fulfil.

This method was soon copied by other Governments and their officials. A specification was established in Germany similar in many details to that prevailing in France, and in course of time other countries followed, including the British Isles; although it may be mentioned that the authorities in this country, with their innate conservatism, were the last to adopt a standard

* See p. 10.

specification, notwithstanding that England was the nursery of the industry. British engineers, architects, and others were in the habit of issuing their own specifications of tests, according to their own particular tastes or individual requirements. These preferences often led to animated discussions between the profession and the manufacturers, sometimes culminating in disagreeable friction. Fortunately this state of affairs no longer exists, a British standard specification being now in force and generally adopted. The British standard specification is too voluminous to insert in this brief descriptive catalogue, but the student will find it in full detail in more than one of the text-books mentioned in the Bibliography at the end of this catalogue. Meanwhile it may be stated that the tests of hardening or setting, and of tensile strains, have always been, and still are, the chief features in the existing specifications both in this country and abroad. The former qualification has already been referred to,* and the latter is illustrated by the foregoing specimens, Nos. 34–39.

The method of testing the tensile strength is the application of a strain to a small block or briquette of cement of standard size, which, after being allowed to set for a definite time, is entirely immersed in water over a given period. The quality of the cement is determined by the increased tensile strength registered at breaking point, when allowance is made for the length of time the briquette has been immersed in water. The specimens just referred to show a regular and gradual increase of tensile strength from 430 lbs. per square inch at 7 days to 1250 lbs. per square inch when 12 months old.

If the raw materials selected for the manufacture of Portland cement are unsuitable, and the proportions

* See p. 26.

inaccurate, or if the process of calcination is imperfect, and the grinding not satisfactory, no amount of manipulation in the testing-room will insure a good tensile strength and progressive increase of strength with age.

Portland cement is rarely used in its pure or "neat" state, it being almost invariably mixed with a proportion of sand or other aggregate, thus forming what is known as Concrete.

It will be manifest, when referring to previous remarks in relation to the importance of fine grinding in the manufacture of Portland cement, that what is known as the "sand test" is especially valuable, because the coarse particles left in the cement, where imperfect grinding occurs, are practically inert material, and thus can only be counted as sand: they therefore increase the proportion of aggregate in the concrete and consequently reduce its strength.

The Specimens Nos. 40–45 are examples of the method of testing with sand, the results showing a gradual rise in tensile strain from 140 lbs. per square inch when broken after being immersed in water seven days, to 550 lbs. when twelve months old.

Portland Cement Concrete

It has just been stated that Portland cement when used for structural purposes is almost invariably employed mixed with sand or some other aggregate forming Concrete, the proportion of aggregate depending on its composition, and on the work for which the concrete is intended. An immense impetus has been given to the uses of Portland cement concrete by the fact that much of the aggregate employed for making the concrete is practically waste material. As evidence of this, examples

of some of the materials in general use are shown in this collection, and will now be referred to in detail.

Nos. 46–51. Specimens of waste materials used for making concrete.

No. 46. **Crushed Granite Chips,** being the débris from granite quarries.

No. 47. **Crushed Fire Bricks,** being refuse material from the linings of smelting furnaces.

No. 48. **Crushed Slag,** being refuse material from blast furnaces.

No. 49. **Coke Breeze,** being refuse material from gas-works and coke-ovens.

No. 50. **Crushed Quartz,** being the refuse material left in the dressing of lead ore.

No. 51. **Crushed Broken Bricks,** being the waste material from brick kilns, and old or condemned brick buildings.

Nos. 52–57. Specimen blocks of concrete made from Portland cement and the above-mentioned refuse materials.

No. 52. **Block composed of 6 parts of crushed granite and 1 part of cement.**

No. 53. **Block composed of 6 parts of crushed fire brick and 1 part of cement.**

No. 54. **Block composed of 6 parts of crushed slag and 1 part of cement.**

No. 55. **Block composed of 6 parts of crushed quartz and 1 part of cement.**

No. 56. Block composed of 4 parts of coke breeze and 1 part of cement.

No. 57. Block composed of 1 part of crushed granite, 4 parts of crushed broken bricks and 1 part of cement.

The following list gives particulars of compression tests of concrete made from some of the above-named aggregates, showing the gradual rise in strength with increasing age.*

Aggregate used	Parts by Measure	Tons per square foot			
		1 month	3 months	6 months	12 months
Granite Chips through ⅜ inch sieve .. Granite Dust .. Cement	4 3 1	132	138	156	161
Slag through 2½ in. ring Sand, very fine .. Cement	5½ 2¾ 1	110	120	130	131
Broken Bricks through 3 in. ring .. .. Sand, fine .. .. Cement	4 2 1	125	154	171	201
Coke Breeze, ½ inch to dust .. .. Cement	3 1	84	92	93	113

* These details have been kindly furnished by Messrs. G. and T. Earle, Ltd., Hull.

Whilst the aggregates represented by the foregoing specimens hold an important position among the materials employed for the making of cement concrete, they are only a few of the almost numberless varieties of material which are equally well adapted for the purpose. Any natural rock that is not actually in a state of decomposition, or exceedingly porous, is suitable, and there are few districts in the habitable world where a useful aggregate cannot be easily procured.

Gravel, either marine or fresh-water, is eminently adapted for concrete making if care be taken that it is free from clay, soft mud, or sewage débris. An excessive proportion of very fine sand ought also to be avoided.

This leads up to the question of the degree of fineness, and the form or shape of the fragments or particles constituting a suitable aggregate. The proportions of coarse and fine aggregate mentioned in the foregoing list of tests may serve as a rough guide, but the materials employed as aggregates are so various in texture, porosity, and specific gravity that it is unwise to formulate a strict code of rules.

Usually experts in concrete construction choose by preference material of an angular shape, which is generally obtained by crushing the broken stone, or other similar material. An assortment of large and small fragments and grains, all alike angular and rough, is the result of this process. Experience has, however, proved that smooth stones in flint gravel are sometimes as good as rough angular fragments, the latter being often more difficult to bed in the plastic matrix.

Spherical pebbles in excess ought to be avoided, especially when there are many present of an equal size. If round marbles all of the same diameter are packed together in a box as closely as possible they occupy only

sixty per cent. of the total space. It is therefore manifest that concrete made up of spherical pebbles of a uniform size must require a large proportion of cementing material to fill the voids in order to form a solid mass.

Sandstones of a micaceous tendency, having flat, laminated texture, and rocks of a slaty structure, ought to be avoided, as they are liable to fracture into thin, flat, wedge-like fragments in the process of crushing, and these do not arrange themselves in a suitable manner to form a solid compact mass when mixed with cement mortar.

Crushed granite, as the foregoing tests demonstrate, is an exceptionally good material as an aggregate, from which a dense concrete may be prepared. Care, however, must be taken that it has not undergone any process of decomposition in nature before quarrying, which, as every geologist knows, sometimes does occur, to a greater or less degree, in many intrusions of igneous rocks, and often these decomposed occurrences, being refused for building purposes, are unfortunately allocated for concrete making, leading to disastrous consequences.

Some compact limestones give excellent results as aggregates when crushed, especially if during the process of reduction a sufficient proportion of finely divided material is obtained, rendering it unnecessary to add any sand. The specific gravity of limestone "dust" is less than ordinary sand, and it is also more homogeneous.

Limestone, however, should be avoided as an aggregate when the concrete is intended for a construction that must resist the action of fire, as, for instance, in the building of safes or strong rooms in banks or public buildings. If a fire occurs the heat acts upon the calcium carbonate in the concrete and forms lime, which quickly disintegrates and falls to powder, bringing about a rapid collapse of the whole structure.

Cinders or coke breeze are generally favoured as aggregates for fire-resisting concretes. The reason for this preference lies in the fact that being porous and full of air they are good non-conductors. On the other hand, although the safe or strong room may be impervious to the action of heat, and therefore useful for the safe custody of documents, the concrete made with coke or cinders is weak and consequently less able to resist burglary.

Coke breeze, however, is also used, like other aggregates, for making ordinary concrete structures, such as those represented by the following examples.

SPECIMENS 58-62, illustrating some of the uses of concrete made with coke breeze.

Presented by The Gas Light and Coke Company, Beckton, North Woolwich.

No. 58. Breeze Concrete Partition Slab.

No. 59. Breeze Concrete Partition Slab, hydraulicly pressed.

No. 60. Breeze Concrete Fence Post.

No. 61. Breeze Concrete Interlocking Building Block.

No. 62. Breeze Concrete Window-Sill.

It should be mentioned that before using the coke breeze it is treated for the removal of sulphur, the presence of which is said to have been responsible for the occasional failure of concrete formed with this material in the past.

When natural gravel, or artificially crushed material, employed for concrete, does not contain a fair proportion

of sand, or crushed stone, in a fine state of division, then a proportion of sand must be added, as will be seen in the details given in the foregoing list of tests.

The size and shape of the grains of sand are important elements to be taken into consideration, and seeing that each grain of sand ought to be entirely coated with cement, to render the concrete impermeable, a coarse sand will give the best results, hence river sand is preferred, as almost invariably it is coarser in the grain than sea sand. The former, however, is frequently mixed with argillaceous matter which ought to be eliminated by washing before being employed for concrete. Peaty, or other organic matter in the sand, should be avoided. The presence of this objectionable matter can easily be detected by rubbing the sand in the hand, and if fine particles staining the hands are visible the character of the impurities ought to be investigated before using the sand.

The presence of salt in marine sand is a feature which, in the opinion of some, condemns it for concrete work. It is generally stated that it retards the setting of the concrete, which is a disadvantage in the construction of maritime undertakings. Moreover, it frequently causes unsightly efflorescence on the surface of the concrete structure. The same reasoning applies when sea-water is used for mixing concrete.

It may be mentioned at this juncture that the action of sea-water on Portland cement is still a matter of controversy among specialists. There seems, however, to be no doubt that if the concrete is at all porous sea-water has a very detrimental effect. Sea-water contains both sulphates and magnesium salts; these act chemically on the calcareous constituents of the cement, causing expansion, which tends to disintegrate the mass. It is

therefore specially important that the concrete should be carefully prepared when employed for maritime work so as to guarantee an impervious structure.

Many instances could be cited where piers and similar maritime structural work have gradually disintegrated, the cause of the failure having been traced to the concrete being porous in places, and the chemical action just referred to operating in the pores of the permeable material. On the other hand, these catastrophes do not diminish the great value of Portland cement in the construction of maritime undertakings, there being numberless examples over the whole world where structures exposed to the action of sea-water have not shown the slightest indication of decay after many years exposure. The harbour works and fortifications at Cherbourg, and the docks at le Havre, both previously referred to in the Historical Notes,* are striking instances.

In heavy and massive concrete structures, very large fragments of stone are often buried in the concrete after it is deposited in position, but this must of course be done before the concrete loses its plastic condition, care being taken also that the large stones, which the workers call "plums," are well covered with concrete. This variety of work is known as "Rubble Concrete," and obviously must effect a large saving in cement. For instance, a cubic foot of stone exposes a total area of six square feet to be covered with cementing material. Divide this cube into 1000 little cubes; it will be just the same weight of material, and it will fill very nearly the same bulk of solid space, but the total area of surface to be covered with cementing material to form a solid mass will now be 60 square feet instead of six square feet.

* See page 10.

Rubble Concrete is extensively employed in the construction of dock walls and breakwaters. A notable instance of this form of construction may be seen on both banks of the Liffey, at the port of Dublin. Blocks of 350 tons in weight were made for the massive quay walls and deposited in position by powerful cranes with the aid of divers. Each block occupies a space twelve feet long by twenty-seven feet high on the quay wall.

Sometimes in exposed situations where a sea-wall or pier is about to be built, huge blocks of rubble concrete, when thoroughly hard, are taken out and tipped into the sea haphazard, thus forming a mound or ridge, on which is built the superstructure. Engineers and others term these "Pell Mell blocks." The sea-walls protecting the harbour of St. Jean de Luz, in the south-east corner of the Bay of Biscay, are an example of this form of construction. The breakwater at Bilbao, on the north coast of Spain, is another instance.

One other form of applying Rubble Concrete in the construction of sea-walls and other similar undertakings is that of moulding the concrete into what is known as "Bag-Blocks." In this system jute canvas bags, sometimes of enormous size, are placed in hopper barges, and there filled with concrete and sewn up. The barge is at once floated out to the site of the proposed sea-wall while the concrete is in a plastic condition. The sack of moist Rubble Concrete is then dropped through a door in the bottom of the barge into position, and the material being still plastic, it adapts itself to the shape of the adjoining bags, dovetailing or interlocking, and thus forming a solid mass. The two breakwaters at the entrance of Aberdeen harbour, built 1870–77, are good examples of this form of construction. In this instance the first

instalment of bag-blocks was laid on the sea-bed, consisting of rough granite, and the plastic bag-blocks by adjusting themselves to the rock irregularities, obviated the labour of levelling the bottom. This form of construction was continued till the bag-blocks rose above low-water mark, and on this the usual type of superstructure was built.

The breakwater at Newhaven is a similar instance. There bags of enormous dimensions were employed, each capable of containing 100 tons of concrete.

For many years Portland cement concrete foundations for paved streets have been largely used and approved of by municipal engineers both at home and abroad. This seems to meet all the requirements essential for a well-laid pavement. It is rigid, thus distributing the load of traffic over a large bearing surface of sub-soil, a feature which also does not allow deformation of the wearing surface, and consequent abrasion of the material forming the super-structure. It is practically impervious to water, thus preventing the moisture which percolates to a greater or less degree through the joints of the surface blocks from reaching the soil of the road bed. It is easily repaired when it becomes necessary to cut into a street for sub-surface connections of any kind; and last, but not least, it is not much, if any, more expensive than the old-fashioned rolled broken stone or gravel foundation. The slow and tedious operation of ramming with a heavy wooden rammer, requiring two workmen to manipulate, is entirely dispensed with. Seeing that the foundation is not exposed to any abrasion, and the weight of the surface traffic is evenly distributed on the foundation, a comparatively poor mixture of concrete can be employed with impunity. Some engineers specify with confidence as low a proportion as 1 part of

cement, 2 parts of sand, and 5 parts of broken stone for pavement foundations.

Quite recently a great impetus has been given to the use of Portland cement concrete for roadway foundations by the adoption of the method of reinforcement which will be referred to when that system is described.

While treating of the manufacture and use of Portland cement concrete, it may be advisable to emphasize that although it is essential that care should be exercised in the selection and preparation of the aggregates employed, it is of supreme importance that the quality of the cement used to form the matrix should be beyond question.

Cement concrete may be classed as an artificial rock, and the same factors which characterise the superiority of natural rocks that are selected for structural purposes, also apply to cement concrete. Students of economic geology are aware that if the interstitial matter between the grains of a sandstone is weak, or lacks cohesion, the stone will be disintegrated when subjected to abrasion, or exposed to the influences of the weather, however strong the grains may be. A rock may consist mainly of quartz grains, and yet be so soft as to crumble when compressed between the fingers; while another rock, having the same general composition, but with the grains firmly cemented together, may be one of the most durable of stones.*

Precisely the same reasoning can be applied to cement concrete; however suitable the aggregate may be, if the cement is weak and unreliable, the whole mass is unsatisfactory.

A few words more may be added with reference to the mixing and application of concrete after the materials

* See *Catalogue of Building Stones*, p. 5.

to form the composition have been properly selected and proportioned. The thorough mixing of the constituents is a most essential feature in the production of good concrete. The different materials ought to be evenly distributed throughout the mass. The respective proportions, which are usually arrived at by measure with what is known as a gauge box, are generally placed on a wooden platform, and turned over two or three times with ordinary shovels. Next water is added, the quantity being chiefly dependent on the nature of the aggregate. It is estimated that the amount of water required for the cement to combine with, and subsequently to crystallise, is about eighteen per cent. by weight; but in practice, as a rule, much more is required to compensate for loss by evaporation, and absorption by the aggregate, especially if a material of a porous nature is employed. The moistened mixture is again turned over with as little delay as possible, and at once placed in position, because, especially in hot weather, the initial hardening or setting process commences almost immediately, *and under no circumstances must cement concrete, which has once begun to harden or set, be re-tempered or re-mixed, either with or without water.*

Mixing machines are sometimes employed in place of manual labour, and have become popular, where a large amount of concrete has to be made on the same site. Many types of machines are obtainable, the apparatus most generally adopted at the present day being a large rotating box or cylinder, resembling somewhat a barrel churn.

It is strange, but nevertheless true, that notwithstanding the perfection that the manufacture of Portland cement has attained, through the application of scientific knowledge and practical experience, coupled with the

stringent conditions, in the form of standard tests and specifications, which are now in force to guard against the possibility of Portland cement of poor quality being placed on the market, cases do still sometimes occur where the resultant work is not wholly satisfactory. In justice to the cement manufacturer, however, it has been proved time and again that the failure has been due to the lack of manipulative skill of the concreter, rather than to the ignorance or negligence of the cement maker. The author of a recently published text-book on the manufacture and uses of Portland cement writes: "After a prolonged and careful enquiry in numerous quarters and over many years, into the value of the practical test in the work as often carried out by the consumer in proving the quality of the cement, it has been found that in eighty-four per cent. of the cases specially investigated, unsatisfactory concrete work has resulted through the faulty *use* of cement." Another writer asserts that ninety per cent. of the failures of concrete are due to poor workmanship, eight per cent. to poor aggregates, and only two per cent. to poor cement. Until structural engineers, architects, and builders are fully alive to the fact that the use of concrete is a science second to none in the art of construction, and must be supervised or handled by experienced and intelligent operators, failures will occur. Why should not the concreter be a craftsman, affiliated with and controlling a distinct branch of industry? Let the art and science of concreting become a subject worthy of the special study of the student of engineering, architecture, and economic geology.

The mixing of Portland cement with mortar has already been referred to, but it may be instructive to mention in this place that a substantial proportion of the

Portland cement now manufactured is used for the improvement or strengthening of lime mortar employed in ordinary structural work. It is true that when a mixture of Portland cement is introduced into lime mortar it is essential that it be used within a comparatively short time after hydration, whereas ordinary lime mortar may be kept for a lengthened period, and, indeed, improves by keeping, in that the process of slaking becomes more complete; but the advantage gained by the admixture of a proportion of Portland cement in lime mortar seems to outweigh the possible disadvantage just cited. The increase in strength which the Portland cement imparts to the mortar is extraordinary, as the following figures show:

Comparative strength under tensile strain of lime mortar and the same mortar mixed with a proportion of Portland cement.

Sand	Cement	Lime	Breaking weight per sq. inch in lbs.
2	—	1	36·89
10	1	0·83	42·34

Thus by adding about the same proportion of cement as lime five times the amount of aggregate can be added without reducing the strength of the mixture.

Fibro-Cement, Known Commerciall as "Fibrent"

SPECIMENS 63–72, illustrating the materials employe in the manufacture, and examples of finished Fibrent

Presented by The British Fibro-Cement Co., Erith, Kent.

No. 63. **Portland Cement,** specially ground an prepared for making Fibrent.

No. 64. **Fibrous Asbestos,** specially prepared fo making Fibrent. THETFORD QUARRIES, WOLFI Co., QUEBEC PROV., CANADA.

No. 65. **Fibrent material moulded for skirting**

No. 66. **Fibrent diamond-shaped patterns,** t illustrate the various colours in which the materia can be manufactured.

No. 67. **Fibrent Slab,** suitable for walls, partitions ceilings, etc.

No. 68. **Fibrent Roofing Slate, natural colour**

No. 69. **Fibrent Roofing Slate, blue.**

No. 70. **Fibrent Roofing Slate, red.**

No. 71. **Fibrent Corrugated Slab,** suitable fo roofing, walls, etc.

No. 72. **Driving screw, limpet, and diamon washers,** for fixing Fibrent corrugated slabs.

It is a debatable question whether this group o specimens should be included among the examples whic appear under the head of Concrete, or under that o Artificial Stone. Seeing that Fibrent is composed mainl

of Portland cement to which is added, as an aggregate, a fibrous variety of serpentine, known mineralogically as Chrysotile, and commercially as Asbestos, it seems consistent to call the finished product a Concrete, bearing in mind that there is no desire on the part of the inventors to imitate stone, or copy the structure or colour of the natural rocks. On the other hand, taking into consideration that many of the features that Fibrent possesses are those inherent in natural stone, some critics might prefer Fibrent to appear under the head of Artificial Stone. The point, however, is immaterial from an economic point of view, and because it appears in the collection among the Concretes, it does not in any sense minimise the importance of this artificial material for structural work.

The term "Fibrent" is a trade name, and the material is also sometimes known as "Fibro-Cement" or "Asbestos-Cement." The components are chiefly Portland cement and Asbestos, and Nos. 63 and 64 are typical examples of these two materials. Special appliances have been introduced in the manufacture, to ensure complete incorporation of the cement and asbestos. The chemical composition, process of manufacture, and cohesive properties of the former have already been referred to in these descriptive notes. The asbestos requires careful selection and preparation, the most suitable form being the fibrous variety of this mineral, known in classical times as Amianthus, which at that epoch was principally derived from Eubœa and Cyprus.

After the materials are thoroughly mixed, enormous pressure is applied, the amount being to a certain extent dependent on the use for which the finished article is intended.

No. 65 is an example of Fibro-Cement Skirting.

Seeing that Fibrent sheets can be cut to any size with an ordinary hand saw, skirtings, dado mouldings, and other internal fittings can be manufactured wholesale and kept in stock to mature ready for immediate use. Indeed, it seems to be within the range of possibility that the time may come when all the fittings of a house, both external and internal, where wood is now employed, such as window frames, doors, staircases, etc., will be manufactured from this fire-resisting material.

Fibrous Asbestos, being a natural mineral, does not as a rule possess any staining property; when therefore it is mixed with the cement, the asbestos-cement concrete or Fibrent retains the original colour of Portland cement; but as has already been explained when describing specimens of ordinary cement concrete, pigments are frequently added to vary the colour without depreciating its quality. The diamond-shaped patterns, No. 66, are typical examples of coloured Fibrent slates or tiles. The grey specimen is the natural colour of Fibrent. The blue example derives its colour from a mixture of oxides. The red-stained specimen is the result of a mixture of red oxide. The purple shade is obtained by a mixture of red and black oxides.

No. 67 is a good example of Fibrent flat sheets, suitable for walls, ceilings, etc. These sheets or slabs can be manufactured in any thickness; the specimen is 3/16 inch thick, and is of the kind usually employed for walls; 5/32 inch sheets are suitable for ceilings. When sheets of the latter thickness are used they are fixed by nailing them to the joists or beams by wide-headed nails, and the joints and nail-heads are hidden by narrow cover strips fixed by small copper or brass tacks. This serves not only to strengthen the work, but to improve its appearance, in that it practically forms a panelled ceiling.

Large quantities of Fibrent sheets have recently been used in this country as well as in France for erecting military huts, hospitals, etc. Many of the huts constructed for the Y.M.C.A. are entirely composed of Fibrent. The Hospital at Chelmsford is an example.

Nos. 68–70 are examples of Fibrent roofing slates. The process of manufacture of this roofing material is identical with that of the sheets or plain slabs just described, except that the material is more highly compressed, thus rendering the slates absolutely impervious to moisture.

The Chelmsford Hospital just referred to is a good example of a building roofed with Fibrent slates. The roofs of Messrs. Vickers' works at Crayford and at Erith are instances of buildings roofed with the red variety of Fibrent flat slates.

A few remarks may now be useful in reference to the advantages claimed by the inventors of "Fibrent" over ordinary cement concrete for walls, or roofing material. Fibrent sheets are made to stock sizes in a locality most favourable for economical manufacture, the works being placed in the centre of the Portland cement industry of the Thames. All sheets are well matured before they are exposed for sale, and can be cut to any size with an ordinary hand-saw. Ordinary concrete walls, on the other hand, must be erected on the site of construction, and by skilled labour. A considerable time elapses before the forms can be removed from the moulded walls, thus delaying subsequent operations. Moreover, since asbestos is fire-resisting to the highest degree, "Fibrent" is said to excel ordinary concrete in fire-resisting capabilities. It is also lighter in weight.

With regard to Fibrent Roofing Slates the student of Economic Geology is referred to remarks contained in

the descriptive catalogue of the specimens of Roofing Slates in the Museum. It is therein explained in detail that the introduction of the thin, tough, smooth, clay-slate roofing material, notably that from the quarries in Wales, served in a great measure to revolutionise the architecture of roofing, thus dispensing with the heavy rafters, strong buttresses, small window openings, and thick walls which were needed to withstand the downward thrust of the heavy roofs covered with lead or stone slabs. When it is claimed that Fibro-Cement Roofing Slates are, when properly manufactured and matured, practically stronger than natural clay or ash slates, and less than half their weight, it is manifest that this comparatively new innovation may lead to a yet lighter and more picturesque style of roofing.

Another advantage claimed by the inventors of Fibrent slate is its capacity for insulating cold and heat better than any roofing material produced from a natural rock or a metal. This property is important, especially in tropical climates. It may interest the student if a few comparative figures are given of the conducting power of various materials employed for roofing :

Cork	0
"Fibrent"	13·9
Natural Slate	46·4
Clay tiles	58·2
Iron	100

As the specimens indicate, the holes requisite for fixing the slates are made in the Fibrent before leaving the works.

No. 71 is a typical example of Fibrent corrugated sheets. This is the latest development in the industry of Asbestos-Cement manufacture, and in the opinion

of some competent to judge, is likely to be the most important branch of the industry. It is hardly necessary to remind the student of Architecture, or, indeed, of any branch of Natural Science, that a metallic body, such as iron sheeting, undergoes an enormous increase in strength by the process of corrugation. Formulæ demonstrating this are given in most engineering text-books. Whether a proportionate increase in strength occurs in Fibrent sheets, when corrugated, has not up to the present been clearly proved, but it is hoped that the day is not far distant when a formula will be forthcoming; and let it be repeated that here is a field of research ripe for the student of economic geology. Meanwhile, it may be mentioned that to the casual observer this material seems to possess one or two self-evident advantages, in comparison with the well-known corrugated iron sheeting for roofing and other purposes, which has held undisputed sway for many years both in this country and abroad.

It is manifest that iron corrugated sheeting is at its best when new, for notwithstanding persistent periodical painting it gradually corrodes and decays; in fact it is generally agreed that the life of corrugated iron seldom exceeds 15 years, or 20 years if under very favourable circumstances. On the other hand, the material from which Fibrent is chiefly manufactured increases in strength with age without any expense or trouble of painting. The lightness of weight and the climatic advantages of this material are other important features, but these have already been discussed when describing the flat sheets of Fibrent.

As in the case of plain sheets, corrugated slabs can be cut with a good ordinary hand-saw, and can be drilled with an ordinary wood brace and bit. When these holes

are drilled a little play ought to be allowed for, in case of slight expansion or contraction of the roofing timbers or angle iron. This can be provided for without interfering with the impermeability of the roofing, by inserting a washer under the head of the driving screw.

No. 72 comprises specimens of driving screws furnished with limpet or diamond-shaped washers, the forms usually employed.

Many buildings of importance that have recently been erected are roofed with Corrugated Fibrent sheets, among them may be mentioned the Whitehead Aircraft Co.'s factory, and Messrs. Daimler's new Works at Coventry.

It may be instructive to mention that Corrugated Fibrent Roofing Sheets have lately been submitted to a test, the sheets being two months old, fixed to rafters with 3 feet 6 inches centres, and they stood a weight of over seventeen stone.

Reinforced Concrete

The use of Portland Cement Concrete has recently been greatly increased by the introduction of Steel Concrete, sometimes known as Ferro-Concrete, or Reinforced Concrete.

Portland Cement Concrete possesses considerable compressive strength, equal if not superior to that of many building stones. It is, however, deficient in shearing strength, and somewhat weak in tensile strength. Ordinary cement concrete therefore cannot be employed without considerable risk in the construction of arches, beams, partition walls, and, in fact, in any form of structural work where stability is essential. If, however, concrete is intersected by a series of parallel rods,

or a net-work of wrought iron or steel, a process termed reinforcing, the tensile strength of the concrete will be increased enormously. Thus this simple method overcomes the weakness of ordinary concrete construction, and the thickness of the concrete arches, beams, or walls, as the case may be, can be curtailed with safety, the saving in material and labour far more than compensating for the extra cost of the metallic insertions, besides giving increased strength to the finished work, and enabling engineers, architects, and others to undertake works of construction by the reinforced method with impunity.

The use of reinforced concrete for railway bridges, where long spans are necessary, has become an important feature in engineering, and may in the future entirely supersede the iron and steel structures at present in vogue. The cost of maintaining a steel bridge, whether it be for railway or road traffic, is much greater than that of a concrete structure. It is estimated that the steel bridge spanning the Firth of Forth, a little west of Edinburgh, requires repainting every third year to prevent corrosion, and that the process of painting occupies fully three years, therefore a staff of painters must always be at work. The metallic portion of reinforced concrete, on the other hand, is entirely protected from atmospheric action.

As evidence to prove the remarkable development of concrete construction for harbour works since the system of reinforced concrete has been introduced, a striking example may be cited.

It has already been mentioned under the head of "Concrete," that large monolithic blocks of concrete were constructed and employed, about twenty years ago, for the new Harbour and Docks of the Port of

Dublin, each block weighing 350 tons. These were then considered to be a marvel of engineering skill and enterprise.*

At present (1917) extensions and improvements are being prosecuted at the Harbour of Valparaiso, on the coast of Chile, by a firm of British engineers. Besides numerous monolithic concrete blocks for the construction of breakwaters, etc., six huge Reinforced Concrete blocks have been constructed. Each one of these may be described as a hollow block or lidless box 66 feet long, 53 feet wide, and 50 feet deep. The sides and bottom are composed of Portland cement concrete reinforced with a network of steel rods. Inside it are five partition walls also made of reinforced concrete, thus forming six compartments. It is constructed in a temporary dry dock, built specially for the purpose, and when sufficiently indurated it is floated into the sea in the same manner as an ordinary ship. The hollow reinforced block, which weighs 2464 tons, is then towed out to the position it is intended to occupy to form a breakwater, where there is a mean depth of water of about 47 feet or three feet less than the depth of the hollow block. Barges loaded with mixed concrete are then sent out and moored alongside the empty reinforced concrete block, and the concrete, in a plastic state, is hoisted up and thrown into the six empty compartments. As they become filled the monolith sinks, and finally rests on the sea-floor, three feet of the block, which is now a solid mass of concrete and ferro-concrete, appearing above water, and forming a base on which to build the requisite superstructure. Each of these colossal monoliths, when set and completely filled, weighs 13,370 tons!

* See p. 62.

Truly the monoliths designed and constructed by Dr. B. B. Stoney, the veteran engineer of the Dublin Port and Dock Board, not twenty years ago, sink into positive insignificance when compared with Messrs. Pearson's Valparaiso reinforced monoliths.

It may interest the student to know that the aggregate employed for making the concrete blocks and forming the rubble foundations at the Valparaiso Harbour works consists of granite from the igneous intrusions which abound in the district. Three quarries are in active operation for the supply of the material, the granite being subsequently reduced by crushing machinery installed specially for these works. One quarry is situated at Las Salinas on the north-east of the Bay, about four miles from Valparaiso, and the other two are at Canchas and Miraflores, both a little distance inland.

The quarries at Canchas and Miraflores yield a dark grey granite showing a slight tendency to gneissic foliation. The rock from the Salinas quarry is distinctly gneissic in structure. This latter variety is chiefly used as rubble in the protective sea works.

These rocks have occasionally been used at Valparaiso for building purposes, but only for foundation work and rubble walling, and that to a very limited extent, therefore specimens do not appear in the "Building Stone" collection of this Museum. The bulk of the houses at Valparaiso are built of brick and plaster.

Reference has already been made to the fire-resisting properties of concrete under certain conditions. Steel reinforcement is an important factor in fireproof work because it enables the concrete to hold together notwithstanding that it may have been cracked by fire and water. Again, the concrete, being a non-conductor, preserves the metallic reinforcement from being softened

or warped when subjected to a high temperature. Moreover it has been proved that the coefficient of expansion of concrete and steel are substantially the same, therefore there is no separation when heat is applied.

It is interesting to follow a theory that has been propounded recently with reference to the capacity of cement concrete for resisting fire. The cement mortar when mixed takes up water to the amount of about eighteen per cent. of the cement contained. This water is chemically combined, but a process of dehydration takes place at a high temperature, say, at about 900° Fahr. This vaporisation of water absorbs heat, and by that means keeps the mass at a comparatively low temperature for a considerable time.*

For many years Portland cement concrete has been an important factor in the construction of iron or steel ships. Almost without exception the keels of iron vessels are lined with a coating of concrete in order to protect the iron or steel of the hull from the corrosive action of the bilge water. Moreover, barges constructed entirely of reinforced concrete have been in use on the rivers of Norway and Italy, and in the Panama Canal zone.

Owing to the shortage of ordinary materials during the war, and the time saved in construction, reinforced concrete was also used to some extent for building sea-going vessels. A fair number were constructed, but the results have not been very satisfactory, and it is doubtful whether under normal conditions ships will be built of this material to any considerable extent.

Concrete reinforced with steel has been largely used in the construction of fortifications in this and other

* Taylor and Thompson, *Concrete, Plain and Reinforced*, p. 290.

countries, in some cases with the addition of armour, and in others without.

The system of Reinforced or Ferro-concrete is believed to have first assumed a practical form in France, and specialists on this subject attribute much credit to one Joseph Moier, a French gardener, who, about the year 1868, was said to have conceived the idea of strengthening the walls of some concrete tanks he was constructing by building in a network of iron rods.

There was, however, more than one attempt to introduce what may be termed Ferro or Reinforced Concrete long before the epoch of Moier's experiments.

W. B. Wilkinson, Master Plasterer, of Newcastle-upon-Tyne, took out a patent in 1854 for concrete floor construction. He provides in his specification that the floor can be strengthened by the insertion of "wire rope (which may be procured second-hand in considerable quantities) or wire in other forms in a state of tension. . . . The wire rope is secured at its extremities at each line of support by embedding it in the mixture of concrete while in a soft state, and forming the ends into loops or by opening out the strands and hirling them in various directions, which renders it so secure as not to be drawn out under any force short of the breaking weight of the rope." Wilkinson does not limit himself to the application of Portland cement, but specifies that plaster or air-slaked lime can be employed. He did not, however, specialise to any extent in his patented form of construction, and his name has never, in the North, been associated with ferro-concrete building. His energies were more directed to the use and perfecting of Portland cement concrete paving slabs, for which he enjoyed a well-earned reputation for many years. He also devoted

much attention to the laying of monolithic concrete pavement for footpaths, and he introduced an ingenious but simple method of avoiding the surface cracks which so often disfigure concrete pavements.

Almost contemporaneously with Wilkinson's discovery, E. Coignet, a contractor of some repute in Paris, took out a patent for a system of Ferro-concrete in 1855. His method of reinforcing was by placing iron rods crosswise, forming a network embedded in the concrete. Coignet constructed twenty-eight arches in the aqueduct of the river Vanne for the Paris water supply, adopting his method of reinforcement. The aqueduct is still in excellent preservation.

A few specimens illustrative of some of the various systems of Reinforced Concrete have been included in this collection, and they will now be described. In some instances only the reinforcement is shown, as the limited space does not admit of examples being exhibited in all cases of the combination of concrete and reinforcement in a practical form. Moreover, even if there had been room it would seem to be redundant to occupy space in exhibiting the concrete as well as the metallic reinforcement, seeing that so far as the concrete itself is concerned there is no difference in its manufacture or in its application to the various systems of reinforcement.

No. 73. Reinforced Concrete Slab.

Presented by The British Reinforced Concrete Engineering Co., Ltd., Manchester.

The particular form of metallic reinforcement in concrete, and the method of application, depend on the type of structural work for which it is intended. This specimen is a typical example of the reinforcement

usually employed for concrete slabs, as in the construction of walls, floors, and foundations, especially the foundations of roadways

The reinforcement embedded in the concrete slab is composed of drawn mild steel rods running longitudinally and transversely, and electrically welded to form a metallic mesh. The rods or wires, as shown in the specimen, are about three inches apart. The additional strength given to the cement by the reinforcement is determined by its size and its position in relation to the concrete, and the relative proportions are arranged to suit the purpose for which the work is designed.

As previously mentioned, reinforcement in the form of mesh or network is specially useful for the concrete foundations of roads. The chief advantage gained is that in many cases the ground on which the concrete foundation is placed is more or less of a soft nature, and the network of reinforcement causes the concrete foundation to distribute itself, as it were, and thus reduce the unit pressure. The combined structure of steel and concrete act together in the same way as the members of a steel girder act together. The reinforcement by itself would not carry the load, neither would the concrete itself, but the strength of each is increased several times for the particular purpose of carrying the load.

No. 74. Experimental Block of Steel Reinforced Concrete.

Presented by R. Edwards, Esq., Cambridge.

Notwithstanding the rapid development of the uses of Reinforced Concrete, there are still some engineers and architects who are not in favour of its employment. One of their objections is that there is a danger of the

reinforcement, whether it be steel or iron, corroding after being embedded in the concrete and eventually decaying away, thus causing disaster.

In order to endeavour to prove the fallacy of this reasoning, a simple experiment was carried out adjoining this Museum, which will be described, and which the specimen represents. In January, 1911, two steel rods, each $\frac{5}{8}$-inch diameter, were embedded in concrete; one was polished and the other slightly rusty. The concrete was composed of four parts by measure of washed shingle, one part of sand, and one part of Portland cement. After the reinforced block hardened it was buried in the ground outside the building in a very moist situation a few inches below the surface. In May, 1913, the block was unearthed, part of the concrete was with difficulty removed, as shown by the lacerated condition of the block, when the steel rods were found to be in exactly the same condition as when embedded two years previously.

The broken block has been exposed to the atmosphere since then, and it will be observed that the steel rods are now corroded where they are uncovered.

To avoid corrosion, care must be exercised not to use more water in the mixing of the concrete than is sufficient to secure complete crystallisation of the cement, which takes place long before the moisture in the newly-mixed cement and aggregate can affect the metallic reinforcement. If the concrete is super-saturated with water then there is a risk of corrosion taking place. Again, if air spaces are permitted to occur in the concrete, owing to inefficient mixing and ramming *in situ*, the oxygen in the air occupying the spaces will attack the reinforcement and corrosion will inevitably ensue. Hence the importance of eliminating any tendency to

permeability in reinforced concrete, it not only being a feature of weakness in the structure, but also a cause of corrosion. This is another instance in the use of concrete of the necessity of the worker being a trained craftsman in the art and science of concreting

No. 75. Indented Steel Bar for Reinforced Concrete.

Presented by the Indented Bar & Concrete Engineering Co., Ltd., London

Besides the objection mentioned when describing the foregoing specimen, another has been put forward by some critics as being detrimental to metallic reinforcement, namely, that in concrete work reinforced with steel rods there is a possibility of the rods slipping in the concrete.

To combat this possible objection "Indented Bars" were introduced. It is obvious, on examining the specimen, that this simple invention does away with this supposed source of failure, hence the frequent adoption of the system in many works of construction. The new reservoir in connection with the city of Perth water supply is a recent instance of the adoption of this system. The donors of the specimen state that they manufacture indented bars from $\frac{3}{8}$ inch to $1\frac{1}{2}$ inches in diameter. The specimen is an example of a $\frac{3}{4}$-inch bar.

No. 76. Expanded Steel for Reinforced Concrete.

Presented by the Expanded Metal Co., Ltd., London and West Hartlepool.

These specimens represent a form of steel meshwork which is frequently employed in the construction of Reinforced Concrete.

It is manufactured in large sheets by special machinery invented for the purpose, and is made by cutting and slitting at regular intervals plain steel plates, which are then forcibly distended sideways until the slits become diamond-shaped openings; the result is a lattice-work of jointless steel, which is known as "Diamond Mesh Expanded Metal." As the specimens show, the method can be adapted to any reasonable thickness of steel plate.

To obtain the full benefit of the tensile strength of this metallic network the sheets must be laid with the long diameter of the meshes from support to support.

Expanded Steel is largely employed for the reinforcing of concrete roadway foundations, and the same reasoning applies to the application of this variety of net or lattice-work reinforcement as was mentioned under the head of specimen No. 73. It was used in the construction of the Stadium at Shepherd's Bush, near London.

No. 77. Model of Keedon System of Concrete Reinforcement.

No. 78. "Keedon Stirrup."

Presented by Messrs. Richard Johnson, Clapham and Morris, Ltd., Manchester.

It has been recognised by engineers and architects that the shear stresses in most forms of reinforced concrete construction are very important factors, and have to be provided for in order to guarantee stability and satisfactory results. The exploiters of the "Keedon" system of reinforcement, represented by the model in the collection, claim that their method, which is said to combine adjustability and rigidity of shear members, is a dependable way of taking up the shear stresses. Furthermore, the method of keying on the stirrup to

the bar, as shown in the specimen stirrup, distributes the diagonal tension of the shear stress to the main bar, and consequently is believed to be more reliable than any form of loose shear member.

The "Keedon" system, it is claimed, can be adapted to all classes of concrete construction, and, as the model indicates, it is evidently particularly well suited for concrete columns, piles, and similar work.

This form of concrete reinforcement has been employed in the construction of the new sheds erected on the Manchester Ship Canal.

No. 79. Patent Hollow Reinforced Concrete Fencing Post.

Presented by Messrs. Tidnams, Ltd., Wisbech.

The rapidly diminishing area of forest cultivation in this country, thus causing home-grown timber to be scarce and expensive, has stimulated the introduction of substitutes, and wooden fencing is now being supplanted in many districts by wire fencing supported by concrete posts.

The specimen is a good example of a section of Reinforced Concrete Fencing Post. It is hexagonal in shape, tapering from 5 inches at the base to 4 inches at the top. It is made with one part of Portland cement to four parts of aggregate, the latter being composed of granite chippings, beach shingle, and sand. It is reinforced with four 5/16th in. steel rods. There are six holes at equal distances in the whole length, through which can be passed plain, galvanised, or barbed wire This form of fencing is now being largely employed by the principal railway companies in this country.

The same form of construction is also used in the manufacture of gate-posts and guide-posts.

There are few, if any, branches of modern industry that can claim to be affiliated with so many patented applications as that of metallic reinforcement to concrete, and the number and variety are being increased every day.

It would go beyond the limits of the allotted space to include in this collection more than a very small proportion of examples of reinforcement, but it is hoped that the few just described, kindly contributed by the respective donors, will give some small idea of what is being generally adopted in this country. Moreover, it is not practicable to furnish formulæ in this brief descriptive catalogue, setting forth the methods of computing the amount or strength of the reinforcement essential for the strains that the reinforced concrete will be called upon to withstand. Exhaustive details will, however, be found in many of the text-books which are mentioned in the Bibliography at the end of this catalogue.

When illustrating the uses of Portland cement it seems incongruous to permit specimens of artificial stone to appear under a title independent of concrete, seeing that the former is a concrete and the latter is undoubtedly artificial stone. Nevertheless, this mode of procedure is almost invariably adopted in the text-books of to-day, concrete being generally classed as a material that is placed *in situ* in a plastic condition, and left to harden and set, with no attempt to make it appear other than what it actually is. Artificial stone, on the other hand, although composed of concrete and moulded into objects by the dozen or thousand in the workshop, is a material in which every effort is brought into play by the craftsman to mould and finish the

work in such a manner as to deceive the eye of the public; and the more perfectly he can imitate the natural rock he seeks to copy, the higher is the value attached to his work.

The sequence of the specimens in this collection has been made to follow this usual course of arrangement, which, by the way, seems justifiable, seeing that the original patentee of Portland cement set forth in his specification that his newly invented cement was suitable for constructing Water Works and similar undertakings, Stuccoing buildings, and manufacturing Artificial stone.

The first-mentioned class of structural work has already been referred to under the head of Concrete. A few remarks will now be made with reference to the use of "Portland" for Stucco, and then Artificial Stone will be dealt with.

Portland Cement Stucco

Very soon after Portland cement was introduced it became popular for stuccoing buildings. The fact of Aspdin, the inventor, mentioning this adaptation in his patent may have tended to stimulate this popularity, especially as he claimed in his specification that it resembled in colour the natural Jurassic rock of Dorsetshire, known as Portland Stone, which at that period was, and still is, in much favour for structural purposes.* Suffice it to say that the popularity became almost a mania, and the outer walls of whole streets of houses were plastered over with a coating of the new Portland cement, even in localities where good building bricks and stone could be obtained in abundance. The joints

* See *Catalogue of Building Stones*, pp. 178, 313.

which appear in walls composed of natural stone, and even the marks of the stone mason's chisel, were carefully imitated on the face of the stucco.

Fortunately this questionable form of decorative art is now on the wane.

There are instances, however, when Portland cement stucco becomes a valuable commodity, if not a necessity. In some districts, both at home and abroad, where stone for building is difficult to procure, the local building brick is resorted to; and sometimes, owing to the nature of the clay used for their manufacture, the product is soft and porous. Then a facing of Portland cement stucco is invaluable as a protective shield against moisture. A striking instance may be cited. Those who have had the opportunity of visiting Johannesburg, in the Transvaal, will have noticed that many of the modern houses are faced with Portland cement stucco. These houses are built of the local bricks manufactured at Claremount, a suburb of the town. Owing to the nature of the clay these bricks are very porous, and therefore unable to resist the action of the torrential rains which occur almost daily during the summer in that region. Portland cement stucco is therefore employed for coating the external walls, and large quantities are annually exported to South Africa from the British Isles to be used for this purpose.

Artificial Stone

No. 80. Stuart's Granolithic Paving Slab.

Presented by Stuart's Granolithic Co., Ltd., London.

The use of Portland cement slabs or artificial flags, for forming the footways of streets, paving court-yards, and for similar works of construction, supplanting the

well-known Caithness and Yorkshire flagstones, has been of importance for many years. This use has been stimulated by the introduction of what is known as "Granolithic Pavement," a simple invention patented by Mr. Peter Stuart of Edinburgh, the adoption of which has to a large extent done away with the slippery tendency which was the chief disadvantage of cement flags. As the specimen shows, the surface is broken by a series of indentations, which are made while the concrete is in a plastic state. Many miles of Granolithic pavement may be seen in Cambridge, testifying to the popularity of this way of covering a footway. Most of that existing in Cambridge, however, has been made *in situ*, which is often considered preferable where the traffic can be conveniently diverted to allow the concrete to harden.

No. 81. Hard York Nonslip Stone.

Presented by the Hard York Nonslip Stone Co., London.

This specimen represents another method of roughening artificial stone paving slabs. Besides the novel plan of roughening the surface, the virtue of this variety of artificial stone is said to arise from the fact that the aggregate is composed of a carefully selected natural rock which is found in the lowest bed of an outcrop of sandstone belonging to the Coal Measures of Yorkshire. The bed occurs below the stratum that yields the sandstone usually known as "Hard York Stone." It is fully described in the catalogue of "Building Stones," and is known commercially as "Silex Hard York Stone." The chemical analysis given in that catalogue indicates that it is almost entirely composed of pure silica. The crushing strain is also phenomenally high.*

* See *Catalogue of Building Stones*, pp. 132, 283.

The slabs are manufactured by mixing specific proportions of crushed chippings of the sandstone, and Portland cement, which are run into moulds, and then subjected to a pressure of 2,000 tons per square foot, which intensifies the solidity of the mass. The slabs are then exposed to the action of the atmosphere for several months to mature.

Spasmodic attempts have been made from time to time to introduce the use of Portland cement for the surface pavement of roadways, both in town and country, supplanting granite, wood, or macadam. In the British Isles, however, up to the present, it has not met with the success anticipated. Cement paving blocks or setts have been proved to be too slippery for ordinary traffic, and when roughened by the granolithic or other methods lately referred to, the pavement is difficult to clean where horse traffic prevails. If motors entirely supersede horses this objection may disappear.

No. 82. Concrete Paving Block, suitable for Composition Pavement. Composed of Portland Cement and crushed Granite.

A combination of Portland cement concrete blocks and wood blocks, known as composition pavement, has been tried with partial success in some districts of England, notably in Staffordshire. An instance may also be seen in York. Bricks or blocks of moulded Portland cement concrete, presenting a perfectly smooth surface, are employed, alternating with wood blocks, both of equal dimensions, and laid in position in the same manner adopted when wood blocks only are used. This forms a road surface as smooth, and practically as noiseless, as a well-laid

wood pavement, with the following advantages. The acknowledged hygienic defects, which have lately condemned the use of wood pavements, are reduced by fifty per cent. The slipping tendency is greatly lessened when compared with wood alone, or cement alone. It has been demonstrated that when two substances, both alike possessing an exceedingly slippery surface, but differing in composition or texture, are placed alongside each other, so that the pedestrian's foot, or that of a horse, rests partially on both, the tendency to slip is diminished enormously, although a lucid explanation of this phenomenon has not yet been given.

The question of the durability, combined with safety, of pavements in town and country has for long been a matter of supreme importance. Vast sums of money are spent annually by County Councils and Borough officials in the maintenance of roadways, which expenditure has increased by leaps and bounds since motor traffic has become general, and he who can introduce a pavement with a guarantee as to its stability and adaptability will be warmly welcomed by surveyors as well as by the public. The incessant repairing of roads, both in town and country, at present prevailing is a perpetual source of anxiety to those responsible for their upkeep, and an annoyance to those using them.

Enlightenment as to the true reason why a composition pavement of the kind just described is not slippery would be of special interest, and here is another field of research well worth the attention of the student of economic geology, because if such were properly understood many natural rocks might be utilised for road and street pavement which at present seem to be unsuitable owing to their slippery surface when smoothed.

No. 83. Model of Artificial Stone Patent Spandril Step.

Presented by The Engraltc Stone Co., London.

This specimen represents a novel and ingenious application of Artificial Stone, composed of Portland cement and sand, in the construction of steps and staircases. The tread of the step is detachable, and, when worn, can be renewed without disturbing the step.

It is interesting to observe that the detachable tread is intersected by narrow slips of hard wood, thus forming a composite surface of cement and wood. This is a good example of the adaptation of what has just been explained as a composition pavement to a staircase instead of a roadway, and by that means minimizing the slippery tendency of a smooth concrete step.

Nos. 84-89. Specimens of Artificial Stone, known as "Victoria Stone."

Presented by The Victoria Stone Co., London.

Nos. 84-86. Artificial Stone Cornices.

No. 87. Fractured Moulded Cornice, shewing the composition.

No. 88. Moulded Spandril Step.

No. 89. Moulded Window-Sill.

Paving slabs, cornices, window sills, steps, and other accessories connected with construction are frequently made of artificial stone. Various improvements have been introduced into this branch of industry that are claimed to enhance the value of the manufactured material. Among others may be mentioned a method

of immersing the moulded ingredients for a specific period in a solution of silicate of soda. The inventor of this process claims that it renders the artificial stone harder and more impervious to the weather. This variety of Portland cement concrete or artificial stone is known commercially as Victoria Stone. The system has been largely employed in the manufacture of paving slabs. The aggregate that has usually been employed is granite from Leicestershire, reduced by crushing to a fairly fine state of division. The slabs are moulded in wooden frames lined with metal, and are so manufactured that both sides are alike, so that when one face is worn the slab can be reversed.

The slabs, or other form of work, after being moulded, are allowed to harden for about a week before being immersed in the silicate solution, in which they must remain for another week. They are then stored for about a month, after which they are ready for use.

The apparatus employed for the conversion of the crude silica into silicate consists usually of a pair of iron-edged vertical millstones to reduce the silica stone. The pulverised material is then put in jacketed boilers together with caustic soda, after which steam of a required temperature is injected, thus completing the process.

Nos. 90–92. Specimens of Artificial Stone, known as "Imperial Stone."

Presented by The Imperial Stone Co., Greenwich.

No. 90. Specimen of Imperial Stone panel with moulded pattern in relief.

No. 91. Specimen of Imperial Stone panel with incised moulding.

No. 92. Specimen of Imperial Stone panel with moulded decorative work in relief.

The process of manufacture of Imperial Stone is almost identical with that of Victoria Stone just described. The moulds used are, however, sometimes made of prepared sand. The comparatively rough surface of sand moulds transmits a correspondingly rough face to the concrete slabs, thus imitating in a striking degree dressed natural stone. This process is very suitable for the manufacture of slabs for panel work and similar decorative construction. The slabs are subjected to the influence of steam while setting, which is said to accelerate the hardening process previous to being immersed in the silicate solution.

Unless the aggregate employed contains colouring matter capable of staining the cement with which it is mixed, Artificial Stone made of Portland cement usually resembles the well-known Portland Stone of Dorsetshire*, hence the name given to the cement by the inventor. Manufacturers of Artificial Stone, however, frequently introduce foreign matter into the finished cement powder before mixing; this must be thoroughly incorporated with the powdered cement before the aggregate is added, in order to imitate stone other than Portland. The specimens 85, 86, 90, 91, and 92 are examples of this treatment. No. 85 has a striking resemblance to the red sandstones belonging to the Keuper beds of the Trias formation in Cheshire, which are largely employed for building.† No. 86 is an excellent imitation of the light reddish-brown sandstone of Co. Antrim, belonging to the Lower Carboniferous system.‡ No. 90 is almost

* See *Catalogue of Building Stones*, pp. 178, 313.
† *Ibid*, pp. 154, 299. ‡ *Ibid*, pp. 126, 277.

identical in colour and general appearance with the fine-grained bright red rock belonging to the Old Red Sandstone of Scotland, which is quarried in Dumbartonshire and Stirlingshire for structural purposes.* No. 91 is a good imitation of the rocks belonging to the Trias formation in Dumfriesshire, which are also largely used for building † No. 92 closely resembles the Robin Hood Sandstone of Yorkshire, belonging to the Coal Measures of that region ‡ The decorative moulding in this last specimen is an excellent imitation of sculptured stone.

No. 93. Bedfordshire Concrete Roofing Tile.

Presented by the Bedfordshire Tile Company, Ltd., Leighton Buzzard.

This is an example of a roofing tile made of coloured concrete. Twenty of these tiles are said to weight not more than one hundredweight, and they are produced in a variety of shades.

It may be instructive to give here a list of the pigments usually employed for the colouring of Artificial Stone made from Portland cement concrete, quoted from a well-known text-book.§

Black; black oxide of manganese, or any carbon black.
White, powdered chalk, or barium sulphate (common barytes).
Red; red oxide of iron.
Pink; best quality crimson lake (alumina base).
Yellow; barium chromate, or yellow ochre.
Blue; azure blue, or ultramarine.
Green; oxide of chromium.
Chocolate; oxide of iron and copper, mixed in proper proportions to arrive at the shade required.

* See *Catalogue of Building Stones*, pp. 113, 266.
† *Ibid*, pp. 156, 302. ‡ *Ibid*, p. 284.
§ Associated Portland Cement Manufacturers (1900), Ltd., *The Everyday Uses of Portland Cement*, p. 112.

Such, then, is a brief description of the specimens of Concrete and Artificial Stone in this collection, the base of which is Portland cement, and it is hoped that the examples shown are fairly typical of the almost numberless applications of this well-known material.

The student may notice, after examining the various specimens and perusing the descriptive notes, that there are two methods of using Portland Cement as Concrete or Artificial Stone: First, that in which it is prepared on the site that the concrete structure is destined to occupy, and then deposited in a plastic condition, and allowed to harden and mature in its final position. Second, the method of preparing and maturing the concrete in manufactories specially set apart for the process of manufacture, the place chosen being preferably near where the cement or the aggregate, or both, can be easily and economically procured, and the finished material of standard forms or shapes then conveyed to the site after being thoroughly hardened and matured. The first-named method is almost invariably adopted for foundations, docks, harbours, bridges and other undertakings of similar nature and magnitude. In the construction of ordinary buildings, however, especially of the nature of cottages or artizan's dwellings, and even in larger houses, the second method is now general, and seems to be gaining in popularity. Nevertheless, a difference of opinion still exists whether this second system is a good one. Some critics contend that manufacturing the finished material in one district and conveying it to another for erection must of necessity mean that both the profit of the manufacturer and that of the builder must be taken into account. This seems to be fair reasoning, but, on the other hand, the builder who undertakes the manufacture of his concrete must furnish

himself with appliances for so doing, the cost of which may go far to nullify the prospective saving he seeks to achieve. There is another important factor to be considered; by the second method the finished material can be properly matured, examined, and tested before being sent to its ultimate destination, which is not so feasible on the site of erection. It has more than once been pointed out in these notes that great importance attaches to satisfactory concrete construction, and that the worker should be a skilled craftsman in the art of concrete making; he will naturally become more efficient if employed exclusively in a special manufacture.

It will also be manifest to the student of Economics that if the structural materials made of concrete, many of which are represented in the collection, are manufactured wholesale to standard sizes, they should and must be made more cheaply than if only a limited quantity were required (say) for the construction of a single house, or even for a single row of houses.

There are, of course, exceptions to every rule; for instance, if the buildings about to be erected are in close proximity to a cement works, or in a neighbourhood where a suitable aggregate can be easily obtained, it may then be more economical to manufacture the concrete on the site of erection; but the fact of the recent remarkable development of works throughout the country, each specialising in some particular form of concrete, either plain or reinforced, proves that the second system is becoming popular.

Blue Lias Lime

SPECIMENS 94–96, illustrating the process of manufacture.

Presented by Messrs. C. Nelson & Co., Ltd., Stockton, near Rugby. .

No. 94. Blue Lias Limestone, STOCKTON QUARRIES, WARWICKSHIRE. (For Chemical Composition, see specimen No. 13, p. 32.)

No. 95. Blue Lias Limestone after calcination.

No. 96. Ground Blue Lias Lime.

Chemical Composition.

CaO 61·17, SiO_2 20·04, Al_2O_3 4·97, Fe_2O_3 6·10, MgO 0·95, SO_3 1·09, H_2O and CO_2 4·03, Alkalies and loss 1·08, Insoluble residue 0·57 = 100·00.

Some may think that these specimens are out of place in a collection of cements; but the analyses will demonstrate that this variety of lime is "eminently hydraulic," therefore, as explained in the introduction to this catalogue, its inclusion may be justifiable.*

The Lias Limestones belonging to the lower part of the Jurassic system, occurring in the Midlands and stretching south-westwards into Wales, are, as previously mentioned, extensively employed for the manufacture of Portland cement.† But long before Portland cement was thought of, this limestone, which is generally known as Blue Lias, owing to its colour, was employed for

* See p. xii. † See p. 32.

making ordinary mortar. Blue Lias contains constituents which render it hydraulic, and it was extensively used in work where hydraulicity was essential. Smeaton used large quantities of lime from the Liassic deposits for the erection of his celebrated Eddystone Lighthouse, which was referred to in the historical notes on Portland cement.* Its employment, however, for this class of work has of late diminished considerably, Portland cement having largely supplanted it.

A few buildings of note may be mentioned where Blue Lias lime has recently been used in London: Victoria Railway Station, Savoy Hotel, Great Central Railway Hotel, and Bethnal Green Infirmary.

* See p. 2.

Selenitic Cement

SPECIMENS 97–102, illustrating the process of manufacture.

Presented by Messrs. C. Nelson & Co., Ltd., Stockton, near Rugby.

No. 97. Blue Lias Limestone, STOCKTON QUARRIES, WARWICKSHIRE. (For Chemical Composition see specimen No. 13, p. 32.)

No. 98. Blue Lias Lime. (For Chemical Composition see specimen No. 96, p. 98.)

No. 99. Gypsum, Calcined. (For Chemical Composition see specimen No. 117, p. 109.)

No. 100. Finished Selenitic Cement.

Chemical Composition.

CaO 58·00, SiO_2 16·00, Al_2O_3 6·00, Fe_2O_3 3·00, SO_2 5·75, CO_2 and H_2O 7·00, MgO 2·00, Insoluble matter 1·00, Alkalies and loss 1·25 = 100·00.

No. 101. Blocks of Selenitic Cement.

No. 102. Selenitic Mortar, being 3 parts of Sand and 1 part of Selenitic Cement.

About the middle of last century Major-General Scott, of the Royal Engineers, discovered that the admixture of a sulphur compound with lime before hydration—especially if the lime contained a specific amount of argillaceous matter, thus possessing the property of hydraulicity—had the virtue of increasing the strength and sand-carrying capacity of the mixed materials when employed as mortar. Scott tried several forms of

sulphur compounds, and eventually adopted a mixture of calcined gypsum, better known as Plaster of Paris. He ground the hydraulic lime along with the plaster to an impalpable powder, and called it Selenitic Cement.

The Blue Lias Lime which has just been described was found to be very suitable for the manufacture of this cement, and is extensively employed for that purpose.

Some manufacturers claim that this cement is superior to any other form of plaster owing to its property of not conducting sound.

The internal walls of the upper floors of this Museum are plastered with Selenitic Cement; and it has also been used at the new War Office, Whitehall; the Catholic Cathedral, Westminster, Keble College, Oxford, and the new University buildings, Liverpool.

Roman Cement

Reference was made to this cement in the brief historical account of cements of the Portland type.*

There are two varieties of this cement, which are known commercially as Light Roman and Dark Roman Cement.

SPECIMENS 103–106, illustrating the manufacture of Light Roman Cement.

Presented by Messrs. C. & T. Earle, Ltd., Hull.

No. 103. Light Roman Cement Stone, SANDSEND, NEAR WHITBY.

No. 104. Light Roman Cement Stone after calcination.

No. 105. Finished Light Roman Cement.

No. 106. Block of Light Roman Cement.

Light Roman Cement is produced from calcareous and argillaceous nodules that are found in the gravel deposits which have been washed out of the Upper Liassic beds of the Jurassic system on the coast of Yorkshire. The specimens were obtained from the gravel and clay pits at Sandsend, a village about three miles north-west of Whitby. It will be observed that they contain numerous fossils, including Belemnites (*B. vulgaris*), Ammonites (*Dactylioceras commune* and *Phylloceras heterophyllum*), and bivalves (*Gresslya intermedia*). There are also fragments of the reptile *Teleosaurus*.

* See p. 3.

These calcareous nodules are calcined in an ordinary lime-kiln, but at a higher temperature than that required for lime burning, although not so intense as to cause vitrification. The calcined material is then ground to a fine powder. This natural cement is much more rapid in hardening, or setting, than the cements of the Portland type, and is now considered much inferior in strength, therefore its reputation has diminished, as that of Portland cement has advanced. Indeed, it is seldom asked for now, and it is difficult to give an instance of its use for very modern construction. About forty years ago it was extensively employed by the late Marquess of Londonderry in the construction of the maritime works at Seaham Harbour. The Duke of Portland also used it about the same period for the restoration of Welbeck Abbey.

SPECIMENS 107–110, illustrating the manufacture of Dark Roman Cement.

Presented by H. W. Anderson, Esq., C.E., London.

No. 107. Septaria (Dark Roman Cement Stone), dredged from oyster beds off FAVERSHAM, KENT.

No. 108. Septaria (Dark Roman Cement Stone), from the ISLE OF SHEPPEY, KENT.

Chemical Composition.

CaO 63·76, SiO_2 17·84, Al_2O_3 6·42, Fe_2O_3 4·13, MgO 4·37, H_2O, etc., 3·48 = 100·00.

No. 109. Finished Dark Roman Cement.

Chemical Composition.

CaO 44·54, SiO_2 19·62, Al_2O_3 10·30, Fe_2O_3 7·44, MgO 2·92, SO_3 2·61, CO_2 3·43, MnO_2 1·57, H_2O 0·25, Insoluble siliceous matter 5·86, Alkalies and loss 1·46 = 100·00.

No. 110. Blocks of Dark Roman Cement.

This variety of so-called Roman Cement is made from Septaria which are obtained from the gravels on the coast of Kent, notably on the Island of Sheppey. These nodules, which are of a fine close grain, pasty in appearance, and having the surface of fracture greasy to the touch, are believed originally to have been embedded in the clay deposits of that district. They are also obtained by dredging off the coast.

The process of manufacture is identical with that of Light Roman Cement which has just been described, and, as in the case of the Light variety, Dark Roman Cement is now seldom used, Portland having taken its place. Before the introduction of Portland Cement, however, so great was the demand for Roman Cement, that in the year 1845 Sir Robert Peel, then First Lord of the Treasury, proposed in the House of Commons to levy a tax on the stone from which the cement was made, fearing its exhaustion, and thus hoping to reserve a sufficient supply for the purposes of Government works. Evidence, however, was brought forward proving the superiority of Portland cement, and the proposed tax was abandoned.

Large quantities of Roman Cement were employed in the construction of the Thames Tunnel, which was engineered by Brunel and completed in 1843.

Owing to the quick-setting property of Roman cement, as compared with Portland, it is sometimes used in maritime works in course of construction for covering newly-laid Portland cement concrete, where the work is likely to be submerged by the tide before the Portland cement concrete has become hardened, and at other times it is employed instead of Portland where the work is exposed for a very short space of time. Roman cement, as a rule, becomes quite hard in five minutes,

and sometimes less. It is, however, much more expensive to use as mortar than Portland, because it must not be mixed with more than an equal proportion of sand.

For this and other obvious reasons Roman cement has never been in general use for concrete work, although there are a few examples still existing. Cottages of Roman cement concrete were built at Harwich in 1841 and at Bridgwater in 1846.

Why Parker called his new invention Roman Cement is not clear. Some assert that English architects and engineers, profiting by the experiments and writings of Smeaton, relied on an admixture of Italian Pozzuolano for rendering lime hydraulic, and it was regularly imported for that purpose. Smeaton mentions in his *Narrative* that he procured Italian Pozzuolano from Southampton. It was therefore probably for this reason that Parker gave his new discovery the name of "Roman Cement."

Gypsum

Although the main object of introducing specimens of Calcium Sulphate, popularly known as Gypsum, into this collection is to illustrate the process of manufacture of the well-known cement Plaster of Paris, as there are several varieties of Gypsum in the collection, it may be useful to refer to the uses of these varieties before describing the specimens which relate to the manufacture of Plaster of Paris.

Nos. 111–116. Specimens representing different varieties of Gypsum.

Presented by Messrs. J. Howe & Co., Carlisle.

Gypsum is a hydrous calcium sulphate, beds of which occur in the Keuper Marls of Derbyshire, Nottinghamshire and Staffordshire. There are also deposits in the Permian and Trias formations of Cumberland and Westmorland.

The beds in the Keuper Marls chiefly furnish a fine granular variety of gypsum known as Alabaster, which is described in the catalogue of *Marbles and Other Ornamental Stones.** The coarser varieties dominate below the St. Bees Sandstones of the Trias deposits of Cumberland, and it is these which will now claim our attention.

No. 111. Gypsum, for the manufacture of Plaster of Paris. COCKLAKE MINES, NEAR CARLISLE.

Formerly the beds at Cocklake were worked as open quarries, which were started fully 100 years ago, but

* See *Catalogue of Marbles and Other Ornamental Stones*, p. 375.

they are now mined on the pillar-and-stall system. Cocklake Mines are situated a mile from Cumwhinton, a station about 4 miles south of Carlisle, on the Midland Railway.

No. 112. Selenite, COCKLAKE MINES, NEAR CARLISLE.

Water percolating through gypseous strata dissolves the calcium sulphate. This is subsequently deposited, sometimes in the form of a crystalline rock yielding thin, transparent plates known as selenite.

It has been found that water containing this mineral in solution is permanently hard and possesses special value for brewing purposes; it is therefore largely used by the brewers in and around Burton-on-Trent, where there are springs of this selenitic water. In districts where this water is not available, it is prepared by dissolving gypsum or selenite in water, which process is known as "burtonisation."

No. 113. Gypsum, suitable for the manufacture of Brown Mineral.

No. 114. Brown Mineral. The foregoing variety of Gypsum ground and ready for paper-making.

No. 115. Mineral White. A superior quality of Gypsum ground and ready for paper-making, commercially known as "Mineral White" or "*Terra Alba.*"

As a rule all deposits of gypsum, especially those occurring in the Trias formation, vary considerably both in colour and quality in the same bed. A single bed may contain varieties suitable for making both the

Brown Mineral and the Mineral White used in the manufacture of paper. The variety employed for making Mineral White invariably overlies that used for Brown Mineral, and in some instances they are separated by a thin layer of the anhydrous calcium sulphate ($CaSO_4$) known as anhydrite. In every case the distinctive mark between the layers is present, although frequently it is infinitesimal.

The process of preparing these varieties of gypsum for paper-making is simple, grinding being the only treatment required.

No. 116. Gypsum. The coarsest variety, ground to a coarse powder, suitable for manure.

The variety of gypsum selected for agricultural purposes is that of coarse texture and dark colour, not because it is superior as a fertiliser, but owing to that quality not being suitable for other industrial purposes, while it is found to be equally efficaceous as an artificial manure. It is usually employed as a top-dressing at the rate of about 3 cwt. per acre, and is specially suitable for light soils.

It is also sometimes employed in the preparation of liquid manure, as a mixture of ground gypsum is believed to be very useful in fixing the ammonia.

Plaster of Paris

SPECIMENS 117–122, illustrating the process of manufacture of Plaster of Paris.

Presented by Messrs. J. Howe & Co., Carlisle.

No. 117. Calcined Gypsum, being the first process for the manufacture of Plaster of Paris.

Chemical Composition.

$CaSO_4$ 93·34, $CaCO_3$ 1·93, Fe_2O_3 and Al_2O_3 1·20, MgO 0·13, H_2O 0·60, Insoluble siliceous matter 2·80 = 100·00.

The calcination of gypsum to form Plaster of Paris must be carried out with great precision. Gypsum, $CaSO_4+2H_2O$, must be heated to a temperature just sufficient partially to dehydrate the calcium sulphate, that is to say, to drive off three-quarters of its combined water, thus forming Plaster of Paris $2CaSO_4+H_2O$. The degree of heat required for this is about 400° Fahr. If the temperature is much above this level, then a very slow-setting cement is produced of little value for the purposes for which it is intended. The calcination is usually performed in ovens, and the resultant material is known as "Baked Plaster." Sometimes, as is common in America, the gypsum is heated in pans or kettles, and it is then known as "Boiled Plaster."

When the baking process is adopted the gypsum is broken into lumps of about the size of a small hen's egg. These are then placed in a heated oven constructed on the principle of an ordinary baker's oven. The process of baking or dehydration extends over about twelve hours, when the lumps are withdrawn and after cooling are ready for grinding.

When the boiling process is performed, which is now becoming more general in this country, the gypsum is first ground, and is then spread in a layer about three inches thick, in a shallow metal pan or dish, which is placed over a fire until the temperature of the ground material approaches boiling point. Ebullition then takes place, and the aqueous vapour given off from the lower portion of the layer causes the whole mass to rise; the vapour little by little escapes until the whole is set free, when the pan is withdrawn from the fire and the newly-formed plaster is ready for use.

Baked Plaster, however, is still preferred by most workers, as it hardens more quickly than the boiled variety.

A recent method, known as the Rotary Cylinder process, has been adopted in America for the calcining of gypsum in the manufacture of Plaster. The cylinder is somewhat similar in form to the Rotary Kiln previously described in dealing with the manufacture of Portland Cement, although it is modified and simpler in its method of working; but as up to the present this process of manufacture has not been adopted in this country, details are not given here.

No. 118. Plaster of Paris. Calcined gypsum ground to an ordinary degree of fineness, the usual type of Plaster of Paris of commerce.

No. 119. Plaster of Paris. Similar to the last example, except that it is of selected raw material, and is ground to a very fine powder after calcination, being known commercially as "Superfine Plaster."

No. 120. Block of ordinary coarse Plaster of Paris.

No. 121. Block of Superfine Plaster.

No. 122. A cast made of superfine quality Plaster.

The process of hardening or setting of Plaster of Paris will now be briefly described.

The Plaster is mixed with just enough water to form a smooth paste. This quantity of water, approximately 25 per cent., is not sufficient to dissolve the whole of it, in fact only a small portion of it is formed into a supersaturated solution of $CaSO_4+2H_2O$. The surplus hydrated calcium sulphate is quickly deposited from the solution, and the water is again set free to dissolve another portion of $2CaSO_4+H_2O$, which is also hydrated and deposited. The process goes on by instalments until the whole of the $2CaSO_4+H_2O$ has been hydrated and crystallises, forming a solid mass. The setting occupies only a few minutes, and is accompanied by a certain amount of heat and expansion.

Plaster of Paris obtained its name in consequence of its being largely manufactured in the neighbourhood of Paris. Extensive deposits of gypsum belonging to the Oligocene system occur close to the city; and the upper beds, which are in some places fully one hundred feet thick, are quarried at Montmartre, to the north of Paris, where the Plaster is largely made. A specimen of French Plaster of Paris does not appear in this collection because the examples of Cements and other materials akin to them are confined to those manufactured in the British Isles.

Stucco or Plaster, however, manufactured from gypseous rocks, was in use long before it was named Plaster of Paris. The Pyramids of Egypt contain plaster

work, executed fully four thousand years ago, made from calcined gypsum; and although the fine white stucco employed by the Greeks in classical times was mainly made from white marble, the product of pure carbonate of lime,* it is possible that stucco manufactured from sulphate of lime was employed by the ancient Greeks as well as by the Egyptians.

This, however, is only conjecture, as definite documentary evidence is not forthcoming. Theophrastus uses the Greek word γύψος to denote not only the raw material we know as gypsum, but also the product of its calcination. For instance, the Palace of Knossos, in Crete, is described as being built of brick, except the lowest course, which was composed of large blocks of gypsum, which suggests that it was the natural rock. On the other hand, the face of the statue of Zeus at Megara is stated to be composed of ivory and gold, clay, and gypsum.

In Roman classical times Pliny and Vitruvius refer to gypsum being used for decorative purposes; this may have been the variety known as alabaster, or it may refer to calcined gypsum in the form of plaster.

Coming down to more modern times, Plaster of Paris must have been in general use in France before the thirteenth century, because it is recorded that when Henry III. of England visited Paris in 1254 he was so impressed with the superior whiteness and fineness of the walls covered with Plaster of Paris that he introduced it into this country for structural purposes. A contract for plastering, dated 1317, is in existence, setting forth that Adam the plasterer, a citizen of London, agrees with Sir John de Bretagne, Earl of Richmond, to find Plaster of Paris wherewith to plaster

* See *Catalogue of Marbles and Other Ornamental Stones*, p. 148.

his hall well and befittingly within and without. In 1519, Hermann, in his *Vulgaria*, writes: "Some men will have their walls plastered, some pargetted and white limed, some rough cast, some pricked, some wrought with plaster of Paris."

During the sixteenth and early part of the seventeenth centuries almost every house of importance that was built was lined and adorned with plaster decorative work, and the avocation of plasterer or stucco worker became an important branch of industry There are many examples of decorative work executed in Piaster of Paris during that period still extant in this country; among them may be mentioned those at Audley End, near Saffron Walden. This house was built early in the seventeenth century by the Earl of Suffolk, and the ceilings in the principal apartments are exquisite examples of plaster work of that period. The fan tracery and its radiating ribs and the pendentives of some of the ceilings in King's College, Cambridge, are other good examples of work wrought in Plaster of Paris at that time.

During the Commonwealth, however, with the Spartan severity of that Puritanical epoch, plaster decorations with many other emblems of luxury were at a discount, and the industry languished so that the trade of a plasterer almost ceased to exist. Indeed, later, at the period of the Restoration, it was found necessary to import French plasterers to execute work required.

In the eighteenth century the industry of plaster decoration revived considerably, and some attribute to the influence of the Brothers Adam the restoration and returning popularity of plaster work during their lifetime.

Examples of the use of Plaster of Paris at the present

date need not be given, as they are so numerous, Plaster of Paris being the material almost universally specified for the stuccoing of walls and ceilings. The chief advantage claimed for it as against lime mortar is that the former dries and hardens so much more rapidly, thus allowing the walls and ceilings to be papered or painted within a few hours of its application, whereas lime mortar, which is usually composed of slaked lime, sand, and hair, sometimes requires as many weeks to harden. The surface of walls stuccoed with Plaster of Paris is also much smoother and harder than those covered with lime plaster. This last-named property is, however, not in all cases an unmixed blessing; and in some instances, where the acoustics of a building, such as a church or a lecture room, is an important factor, the hard wall surface is positively a grave objection.

Proofs of this frequently occur in new buildings. It will be found that a building which has been hastily completed and at once occupied for public purposes will for some considerable time fail to give satisfaction as regards its acoustic properties; although ultimately, as the walls lose their moisture, the defects disappear. The reason is obvious. While the walls retain the moisture the cells in the plaster are full of water, but in course of time this evaporates, leaving the cells empty and rendering the walls absorbent, thus reducing reverberation. When this has been understood by those responsible, drapery has sometimes been hung about the walls while the plaster remained moist, and removed when the walls became quite dry.

Here, then, is a factor which some critics believe has not claimed the attention and study that it deserves. Many buildings are coated internally with the quickest setting plastering material procurable, the object being

to have the building ready for occupation as soon as possible, and to render the surface of the walls more suitable for decoration, quite regardless of acoustics.

Although by far the largest proportion of the cements of the Plaster of Paris type is used for structural purposes, a considerable quantity is employed in the manufacture of pottery for mould making, and it is sometimes known in the Staffordshire Pottery districts as "Potter's Stone." It is also freely used by sculptors, for surgical work in hospitals, and in dentistry.

Plaster of Paris is now being employed in the United States for the manufacture of roofing slates or tiles. This form of roofing material, however, has not found favour in this country up to the present, where natural roofing slates can be obtained in abundance.

Keene's Cement

SPECIMEN 123–128, illustrating the process of manufacture.

Presented by Messrs. J. Howe & Co., Carlisle.

No. 123. Gypsum (Sulphate of Lime).

No. 124. Alum.

No. 125. Calcined Gypsum. (For Chemical Composition see specimen 117, p 109).

No. 126. Keene's Cement, ordinary quality.

No. 127. Keene's Cement, superfine quality.

No. 128. Block of Keene's Cement.

Keene's Cement, a name given by the inventor, R. W. Keene, who patented the process in 1838, may be classed as a superior Plaster of Paris, in that it is much harder when set, and consequently more durable, although it takes longer to harden. It is specially suitable for moulding, the sharpness of the castings made from it being due to the slight expansion of the material during the process of setting. Owing to its superior hardness over plaster of Paris it is peculiarly well adapted for making skirtings, columns, pilasters, and similar work that is liable to abrasion. It must, however, be remembered that on account of its superior hardening properties over lime mortar, or even ordinary plaster of Paris, it suffers from the same disadvantage even in a greater degree than plaster of Paris, when used for covering walls, as regards the acoustics of the room where it is employed.

Some writers assert that owing to the hardness of Keene's cement it can be used for external work with

impunity, but this is contradicted by other well-known authorities, and it is affirmed by experienced investigators that all cements having calcium sulphate as their base are not suitable for external work because of the solubility of this substance.

The process of manufacture of Keene's cement is simple, sulphate of lime in the form of gypsum being the foundation. The gypsum, which ought to be the whitest variety, is subjected to a moderate heat, as in the preparation of plaster of Paris, lately described. The calcined material is then immersed in a solution of alum, one part of alum crystal to about twelve parts of water being the usual strength of the solution. The proportion of alum to that of calcined gypsum is generally estimated to be ten parts of gypsum to one part of crystal alum.

The saturated calcined gypsum is again calcined in an oven, care being exercised that the flame heating the oven does not impinge on the material to be calcined. This second process of calcination must be at a much higher degree of temperature than when the raw gypsum alone was treated, 1000° Fah. being the degree aimed at. The result is a light cream-coloured stone which is easily ground, and when set hard, as the specimen No. 128 shows, is capable of taking a good polish. One authority asserts that, unlike other cements, Keene's cement may be reworked with water, even after the setting or hardening has commenced, and will take its set just as satisfactorily as if the process of hardening had not been interrupted.*

Keene's cement is said to be specially suitable for jointing internal marble work.

* E. C. Eckel, *Cements, Limes, and Plasters*, p. 77.

Sirapite Plaster

SPECIMENS 129–136, illustrating the process of manufacture.

Presented by the Gypsum Mines, Ltd., Mountfield, Robertsbridge, Sussex.

No. 129. Grey Gypsum, MOUNTFIELD MINES, near ROBERTSBRIDGE, SUSSEX.

Chemical Composition.

$CaSO_4$ 89·13, $CaCO_3$ 8·90, Fe & Al 0·35, MgO 0·42, SiO_2, Alkalis & loss 1·20 = 100·00.

No. 130. White Gypsum, MOUNTFIELD MINES, near ROBERTSBRIDGE, SUSSEX.

No. 131. Fibrous Gypsum, MOUNTFIELD MINES, near ROBERTSBRIDGE, SUSSEX.

No. 132. Mountfield Sirapite Plaster, being Grey Gypsum calcined and ground.

Chemical Composition.

$CaSO_4$ 85·44, $CaCO_3$ 7·60, CaO 1·50, Fe & Al 0·92, MgO 0·54, H_2O 1·50, SiO_2, Alkalis & loss 2·50 = 100·00.

No. 133. Specimen Block of Mountfield Sirapite Plaster.

No. 134. Pink Gypsum, KINGSTON MINES, near KINGSTON-ON-SOAR, DERBYSHIRE.

Chemical Composition.

$CaSO_4$ 92·65, $CaCO_3$ 3·73, Fe & Al 1·74, MgO 0·53, SiO_2 Alkalis & loss 1·35 = 100·00.

No. 135. Kingston-on-Soar Sirapite Plaster, being Pink Gypsum calcined and ground.

Chemical Composition.

$CaSO_4$ 89·17, $CaCO_3$ 4·53, CaO 1·42, Fe & Al 1·12, MgO 0·64, H_2O 1·20, SiO_2, Alkalis & loss 1·92 =100·00.

No. 136. Specimen Block of Kingston-on-Soar Sirapite Plaster.

The South Downs in the county of Sussex consist mainly of Chalk, but in some districts these beds have been denuded, exposing the underlying rocks. The oldest rocks thus brought to light along the crest of the Wealden anticline, are the Purbeck beds and some important deposits of gypsum which lie north of Battle. The latter have been mined and the yield has for many years been employed for the manufacture of plaster of Paris and other gypseous cements. Some of these beds are intercalated with veins or films of grey material which is unsuitable for the manufacture of plaster of Paris owing to its colour; it therefore was rejected, and large quantities were thrown away as useless. The exploiters of the Plaster works at Mountfield, however, in the year 1891, after exhaustive experiments, invented a method of utilising this waste material, and introduced a variety of plaster of the cement type of gypsum hard plasters, although not identical with other kinds then on the market. This they called Sirapite, sometimes known as Siraphite, and it has been generally approved by architects and others. The term "Sirapite" is without any meaning, and was invented to conform with the requirements of the Trade Marks regulations. Locally, the Sirapite stone is spoken of as "Dobson," this being the name of a builder's merchant who was

one of the first to deal in this new material in any quantity.

The process of manufacture of Sirapite is simple. The gypsum is sorted, crushed, and then calcined at a temperature approaching red heat, which can be estimated at about 1000° Fah. It is afterwards ground and dressed, and is then ready for use. Instructions as to the proper application of Sirapite on walls, ceilings, &c., are many and various, depending on the particular description of work it is intended for, and are too voluminous even to summarise in these brief notes; but the vendors of this comparatively new cement plaster have published an excellent booklet, in which are set forth in detail all instructions as to its application under various conditions, and it would be worth while for the student of economic geology and architecture to read it. In the book of instructions there is also given a long list of buildings where Sirapite has been employed, both at home and abroad, since its introduction to the building world, these are also too lengthy to enumerate here, but a few may be mentioned, with some of the dates when the cement plaster was employed. In the reconstruction of the wards and additions to the London Hospital (*c.* 1901–3), Charing Cross Hospital, the Coliseum, and the Grand Hotel, London; King's College, Aberdeen; the Royal Naval Hospital, Malta (1902); Government works at Gibraltar and Jamaica; King Edward's Mansions, Port Elizabeth (1904–5); and Kiawarawara Post Office, New Zealand (*c.* 1912).

Specimens Nos. 130 and 131 represent varieties of gypsum that are found in the Mountfield Mines, but are not employed for the manufacture of Sirapite. They may be of interest, however, to the student of geology and other branches of natural science. The

pure white crystalline specimen is that which is usually employed for the manufacture of superfine plaster of Paris. The fibrous specimen is used with other gypsum for making plaster of Paris. It is found in bands which bound the working seams both at the top and bottom. These bands have crystallised nearly vertically, and the bands differ in depth from about 1 inch to 3 inches in places. Where the gypsum seams are good these bands recede from each other, the upper band rising and the lower band descending. Where the gypsum is of a lower grade these two bands approach each other, and the gypsum between them is found mixed with calcareous rock

The Keuper marls in Derbyshire, besides yielding the highly decorative variety of calcium sulphate known as Alabaster,* furnish a variety of gypsum well known in the Midlands, which has already been referred to, and which the analyses prove is not the same chemically as that found in Sussex. The donors of the specimens from Sussex also own mines in Derbyshire at Kingston-on-Soar, a few miles south of Derby, where they manufacture Sirapite. The specimens indicate that the Derbyshire variety of gypsum suitable for the manufacture of Sirapite possesses a pink shade, and it will be seen that this colour is also transmitted to the finished cement plaster.

* See *Catalogue of Marbles and Other Ornamental Stones*, p. 375.

Bibliography

Adams & Matthews, *Reinforced Concrete Construction.* (1911.)

Asch, W., *The Silicates in Chemistry and Commerce.* (1913.)

Associated Portland Cement Manufacturers, Ltd., *Everyday Uses of Portland Cement.* (1913.)

Ball, J. D. W., *Reinforced Concrete Railway Structures.* (1913.)

Bamber, H K , *Portland Cement: Its Manufacture, Use and Testing, Proc. Inst Civil Engineers,* Vol. CVII, 1891–2, pt i, p. 31

Bamber, H. K G , *Portland Cement and the question of its Aeration, Proc. Inst. Civil Engineers,* Vol. CLXXXIII, 1910–11, pt. i, p. 85.

Blount, B , *Recent Progress of Portland Industry, Journ. Chem. Industry,* Vol XXV, 1906, p. 1022.

Blount & Bloxham, *Chemistry for Engineers and Manufacturers,* 2nd ed (1905)

Brown, W. A , *Portland Cement Industry* (1916.)

Buel & Hill, *Reinforced Concrete Construction.* (1906.)

Butler, D. B., *Portland Cement.* (1913.)

Cantell, M. T., *Reinforced Concrete Construction.* (1912.)

Cochran, J. A , *Treatise on Cement Specifications.* (1913.)

Concrete & Constructional Engineering, issued monthly.

Davis, A. C., *Portland Cement,* 2nd ed (1909)

Desch, C. H., *The Chemistry & Testing of Cement.* (1911.)

Eckel, E. C , *Cements, Limes, and Plasters.* (1905.)

Faber & Bowie, *Reinforced Concrete Design.* (1912.)

Faija, Henry, *Portland Cement.* (1884.)

Gatehouse, F. B., *Handbook for Cement Works Chemist.* (1908.)

Jones, B. E., *Reinforced Concrete.* (1913.)

Lakeman, A., *Concrete Cottages.* (1918.)

Marsh, C. F., *A Concise Treatise on Reinforced Concrete.* (1909.)

MARTIN, N., *The Properties & Design of Reinforced Concrete.* (1912.)

MELAN, J., *Plain & Reinforced Concrete Arches.* (1915.)

MIDDLETON, G. A. T., *Building Materials,* 2nd ed. (1915.)

MILLAR, W., *Plastering, Plain & Decorative,* 3rd ed. (1905.)

MUNBY, A. E., *The Chemistry & Physics of Building Materials.* (1909.)

PASLEY, Sir C. W., *Limes & Calcareous Cements.* (1847.)

REDGRAVE & SPACKMAN, *Calcareous Cements,* 2nd ed. (1905.)

REID, HENRY, *Portland Cement.* (1877.)

RICE & TORRENCE, *Concrete Blocks.* (1906.)

RICHARDS & NORTH, *A Manual of Cement Testing.* (1913.)

RINGS, F., *Reinforced Concrete Bridges.* (1913.)

Rivington's Series, Notes on Building Construction, Pt. III, *Materials,* 7th ed. (1910.)

ROGERS, A., *Industrial Chemistry,* 2nd ed. (1915.)

SABIN, L. C., *Cement & Concrete.* (1906.)

SEARLE, A. B., *Cement, Concrete, & Bricks.* (1913.)

SLOCUM & HANCOCK, *Text-Book on the Strength of Materials.* (1906.)

SMEATON, J., *A Narrative of the Building of Eddystone Lighthouse.* (1791.)

SUTCLIFFE, G. L., *Concrete: its Nature & Uses,* 2nd ed. (1905.)

TAYLOR & THOMPSON, *Concrete: Plain & Reinforced,* 3rd ed. (1916.)

TURNEAURE & MAURER. *Principles of Reinforced Concrete Construction.* (1907.)

TWELVETREES, W. N., *Concrete Steel Buildings.* (1907.)

WARREN, F. D., *Reinforced Concrete.* (1906.)

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